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Nevada Univ., Las Vegas

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To protect, manage, and use forest resources effectively, the condition of these resources must be known. Concern about documented and potential effects of air pollutants in combination with other multiple, interacting stresses has been a major impetus behind the development of monitoring programs in forests. During the past two years, the forest component of the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP-Forests) has been working closely with the Forest Service's Forest Health Monitoring (FS-FHM) program and other government agencies to develop a multi-agency program to monitor the condition of the nation's forested ecosystems.

The purpose of this document is to present a strategy that can be used as a starting point by all government agencies interested in participating in a nationwide FHM program. Monitoring issues such as design, indicator selection, and assessment are presented along with approaches to resolving these issues.

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ACRONYMS

ADQ - audits of data quality
ADP - automated data processing
AFA - American Forestry Association
AREAL-RTP - Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, North Carolina
ARNEWS - Acid Rain National Early Warning System (Canada)
BIFC - The Boise Interagency Fire Center
BLM - Bureau of Land Management
C - element of carbon
cdf - cumulative distribution function
CPR - cardio-pulmonary resuscitation
DBH - diameter at breast height
DDRP - Direct/Delayed Response Project (acid deposition)
DLG - digital line graph
DQO - data quality objective
DRIS - Diagnosis and Recommendation Integrated System
DSI - data set index
EIC - EMAP information center
EMAP - Environmental Monitoring and Assessment Program
EMSL-LV - Environmental Monitoring Systems Laboratory, Las Vegas, Nevada
EPA - U.S. Environmental Protection Agency
EQO - ecosystem-level quality objectives
ERL-C - Environmental Research Laboratory, Corvallis, Oregon
FHM - multi-agency forest health monitoring program
FIA - Forest Inventory and Analysis (USDA-FS program)
FIC - Forest Information Center
FPM - Forest Pest Management (USFS)
FRP - Forest Response Program (USFS)
FS - USDA Forest Service
FS-FHM - USDA Forest Service ongoing forest health monitoring program

FWS	-	Fish and Wildlife Service
FY	-	fiscal year (federal:October 1 - September 30)
GIS	-	Geographic Information System
GPS	-	Global Positioning System
HT	-	Horwitz-Thompson estimation formulas
IAG	-	Interagency agreement
IFB	-	fixed price contract
IM	-	information management
IQO	-	indicator-level quality objectives
K	-	element of potassium
LQAO	-	Laboratory Quality Assurance Officer
LTER	-	long-term ecological research
MOI	-	memorandum of intent
MQO	-	measurement-level quality objectives
MSR	-	management systems review (audit)
N	-	element of nitrogen
NAPAP	-	National Acid Precipitation Assessment Program
NE-FHM	-	New England forest health monitoring
NQAO	-	National Quality Assurance Officer
NAS	-	National Academy of Science
NFS	-	National Forest System units
NOAA	-	National Oceanic and Atmospheric Administration
NPS	-	National Park Service
NRC	-	National Research Council
NVS	-	National Vegetation Survey (USFS)
ORD	-	Office of Research and Development (USEPA)
P	-	element of phosphorus
PAR	-	Photosynthetically Active Radiation
PDR	-	portable data recorder
PEA	-	performance evaluation audits
QA	-	quality assurance
QAARW	-	quality assurance annual report and workplan

QAC - quality assurance coordinator

QAMS - quality assurance management staff

QAPjP - quality assurance project plan

QAPP - quality assurance program plan

QC - quality control

RDBMS - Regional Data Base Management System

RPA - Renewable Resources Planning Act

RQAO - Regional Quality Assurance Officer

RQO - resource-level quality objectives

RFP - competition negotiation

SAB - Science Advisory Board

SAF - Society of American Foresters

SCS - USDA Soil Conservation Service

SI - le Systeme International d'Unites (standard scientific units of measure)

SOP - standard operating procedure

TC - Technical Coordinator

TD - Technical Director

TQM - total quality management

TSA - technical systems review (audit)

USDA - U.S. Department of Agriculture

USDA-FS - U.S. Department of Agriculture, Forest Service

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1 INTRODUCTION

To protect, manage, and use forest resources effectively, the condition of these resources must be known. Concern about documented and potential effects of air pollutants in combination with other multiple, interacting stresses has been a major impetus behind the development of monitoring programs in forests. During the past two years, the forest component of the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP-Forests) has been working closely with the Forest Service's Forest Health Monitoring (FS-FHM) program and other government agencies to develop a multi-agency program to monitor the condition of the nation's forested ecosystems. In this document, this future multi-agency program will be simply referred to as the Forest Health Monitoring (FHM) program.

The purpose of this document is to present a strategy that can be used as a starting point by all government agencies interested in participating in a nation-wide FHM program. Monitoring issues such as design, indicator selection, and assessment are presented along with approaches to resolving these issues. We ask your assistance in evaluating whether or not these approaches are sound and the strategy is adequate to evaluate the ecological condition of our nation's forests.

The purpose of this introductory section is to provide an overview of the scope and purpose of this document. The contents of each section will be reviewed. An overview of the overall Environmental Monitoring and Assessment Program (EMAP) will be provided along with the fundamental research questions motivating the development of the program. Specific EMAP-Forest goals and objectives designed to answer these questions for forested ecosystems will be presented. A short historical background of the development of the EMAP-Forests program and the FS-FHM program will be given to help the reader put the present planning process in perspective. An important theme of this section is that a multi-agency FHM program can be successful only through effective coordination.

1.1 CONTENT AND ORGANIZATION OF EMAP-FORESTS STRATEGY PLAN

This plan is organized into twelve sections. Sections 2 - 7 present the scientific approach currently proposed for the establishment of a forest health monitoring (FHM) program, including design, indicators, and assessment concepts. Sections 9 - 11 present aspects of logistics, quality assurance (QA), and information management (IM). A description of each section follows:

- Section 2. Approach and Rationale - highlights the overall proposed strategy for EMAP-Forests.
- Section 3. Strategy for Indicator Development and Implementation - explains the process for selecting and testing indicators of forest condition.
- Section 4. Strategy for Monitoring and Network Design - describes the statistical issues related to sampling of forests on a regional basis.
- Section 5. Strategy for Field Sampling Design - describes specific design issues related to plot establishment.
- Section 6. Strategy for Statistical Estimation and Analysis - details the statistical approach for the evaluation of status and trends of indicators.
- Section 7. Strategy for Assessment- depicts the strategy for integrating the statistical information into ecologically meaningful statements regarding forest condition.
- Section 8. Quality Assurance Program - identifies a total quality management

(TQM) approach to ensure that the data collected are of sufficient quality to meet the data quality requirements of the data users.

- Section 9. Logistics Approach - explains a strategy for conducting a field program of this magnitude.
- Section 10. Strategy for a Joint Information Management System - defines how information management supports data collection, data evaluation, and reporting functions.
- Section 11. Strategy for Reporting - describes the type and organization of reports needed to disseminate information to clients.

1.2 OVERVIEW OF EMAP

As the 1990s begin, the United States has begun the task of protecting the integrity and sustainability of the nation's ecosystems. This is critical because the incidence and scale of reported environmental problems have increased during the past two decades. Scientists and the general public are increasingly concerned about environmental problems such as global climate change, acidic deposition, and loss of biological diversity. Scientific studies have heightened environmental awareness and indicate that ecological processes determining how ecosystems respond to natural and anthropogenic disturbances are complex.

Research has also framed several fundamental questions about the severity of these disturbance effects and whether or not they are changing in response to government policies. Unfortunately, the answers to these questions are not readily apparent because the status of the nation's environment is not well documented. A baseline is needed against which we may evaluate measured changes in the condition of resources and the overall effectiveness of national environmental policies.

In 1988, the U.S. Environmental Protection Agency's (EPA) Science Advisory Board (SAB) recommended the implementation of a program to monitor ecological status and trends and to develop innovative methods for anticipating emerging environmental problems before they reach crisis proportions. In response to these recommendations, EPA's Office of Research and Development (ORD) began planning the Environmental Monitoring and Assessment Program (EMAP). Several key questions were formulated to guide the program toward meeting the goals set by the SAB:

1) What is the current extent of our ecological resources, and how are they distributed geographically?
2) What proportions of the resources are currently in acceptable ecological condition?
3) What proportions are degrading or improving, in what regions, and at what rates?
4) Are these changes correlated with patterns and trends in environmental stresses?
5) Are adversely affected resources improving in response to control and mitigation programs?

In 1989 an EMAP approach emerged to address these questions. The EMAP approach will be presented in greater detail in Section 2 of this document, but the basic tenets are presented below:

1) Monitoring should be on a broad regional scale to provide quantitative and unbiased estimates of status and trends in ecological condition.
2) All ecological components of the landscape in all regions should be monitored (i.e., there should be no "orphan" ecosystems).
3) Successful implementation will require a long-term commitment.
4) The scope of the program will require a multi-agency effort.

5) The analysis of ecological condition will require measurements of habitat condition, pollutant sources and exposure, and biological condition.
6) The program will need to focus on ecology as well as traditional monitoring activities.

EMAP comprises seven ecological resource groups: Agroecosystems, Arid Lands, Forests, Great Lakes, Near Coastal Systems, Surface Waters, and Wetlands. The goal has been to ensure that EMAP monitors all major ecological resources. The planning efforts in these resource groups are supported by a number of cross-cutting activities such as design or logistics. This document describes the development of EMAP-Forests toward the FHM program.

1.3 GOALS AND OBJECTIVES OF EMAP-FORESTS

To focus the EMAP-Forests program development, goals and objectives have been specified. The overall goal of EMAP-Forests is to develop and implement a program to monitor, evaluate, and report on the long-term status and trends of the nation's forest ecological resources as these resources relate to changes in and among natural phenomena, resource management practices, and pollutants across the landscape.

To coordinate EMAP-Forests efforts with those in other terrestrial resource groups (EMAP-Arid Lands and EMAP-Agroecosystems), forest land has been defined as land with at least 10 percent of its surface area stocked by trees of any size or formerly having had such trees as cover and not currently built up or developed for agricultural use (USDA Forest Service 1989).

For purposes of clarity, a tree has been defined as a woody plant with one or more perennial stems at least three inches in diameter at breast height at maturity, with a more or less definitely formed crown of foliage and a height of at least sixteen feet at maturity (USDA Forest Service 1989).

It is important to review the overall goal and highlight certain aspects. Although the EMAP-Forests definition of forest land is based on trees, the goal of EMAP-Forests is to assess the health of forested ecosystems and not just trees. This assessment must be based on components of forest condition that reflect the variety of values which society associates with forests. Societal values include the variety and abundance of plant and animal life, clean air, clean water, and fertile soils. Forested ecosystems have traditionally provided economic values for those who directly or indirectly derive their livelihood from the utilization of forest resources. The values which society now places in many forests for recreation, aesthetics, and a place to observe nature in its pristine state are also important considerations for EMAP-Forests.

Many times, these different values result in conflicts regarding the management of forest lands and the assessment of health or condition. For example, an old growth forest may not be as efficient as a newly planted forest in capturing light and converting it to wood production, but it may be valued for its habitat for certain types of wildlife. EMAP-Forests must obtain objective measures of all values society places in forests.

In addition to assessing forests for ecological and societal values, EMAP-Forests also intends to assess the various stresses on forested ecosystems. These include natural stresses such as climate, pests, and anthropogenic stresses (i.e., management action and pollution). The evaluation of pollutant stresses and their relationship to forest condition are of particular importance to EMAP-Forests and the EPA.

The overall goal has been developed into some specific objectives. These detailed objectives, which are presented in the following subsections, have been designed to parallel the overall EMAP objectives which are:

1) Estimate the current status, extent, changes, and trends in indicators of the condition of the nation's ecological resources on a regional basis with known confidence.
2) Monitor indicators of pollutant exposure and habitat condition and seek associations between human-induced stresses and ecological condition.
3) Provide periodic statistical summaries and interpretive reports on ecological status and trends to resource managers and the public.

1.3.1 Short-term, Mid-term, and Long-term Objectives of EMAP-Forests

1.3.1.1 Status and Trends of Ecological Resource Indicators

EMAP-Forests will provide unbiased, regional estimates of the status and trends of indicators of ecological resources in forests, which includes productivity (food and fiber), animal diversity, plant diversity, water quality, and aesthetics on an annual basis for all ecoregions of the United States.

1.3.1.1.1 Short-term Objectives (1-5 years)

By 1995, EMAP-Forests will resolve the following technical issues:

- Development of a conceptual framework for integrating indicator information into assessment endpoints representative of all values placed in forests.
- Resolution of frequency of plot sampling.
- Strategy for evaluating indicators as to their accuracy in representing ecological condition and pollutant exposure.
- Plot design for uniform and non-uniform stands.
- Evaluation of multi-stage remote sensing for characterizing landscape processes.
- Linkages of landscape indicators with plot level indicators.

By 1995, EMAP-Forests will develop an effective forest health monitoring program that:

- Is a multi-agency program with the FS and other federal and state agencies.
- Has the active support of EPA line management at participating EPA laboratories.
- Has an efficient indicator development program which includes the participation of the outside scientific community in identifying and testing of new indicators.
- Is characterized by the collection of high quality data through the coordinated activities of QA, logistics, and information management.
- Meets the needs of data users through rapid turnaround of data by electronic capture, transfer, and easy access.

By 1995, EMAP-Forests will develop as products of forest health monitoring:

- A set of at least four core indicators with documented spatial, temporal and measurement components of variance and detailed methods manuals for each region.
- Annual statistical summaries of the status and trends for these indicators in regions where forest health monitoring has been implemented.
- A QA program plan and associated project plans for each region.

1.3.1.1.2 Mid-term Objectives (6-10 years)

By 2000, EMAP-Forests will improve technical capabilities of the program by:

- Testing additional indicators for incorporation into the set of core indicators.
- Expanding the multi-agency forest program to include all other forest land management agencies.
- Providing interpretive assessments on critical endpoints for U.S. forests.
- Improving ability to obtain indicator information from satellites such as NASA EOS.

1.3.1.1.3 Long-term Objectives (11+ years)

By 2005, EMAP-Forests will demonstrate the effectiveness of the forest health monitoring program by:

- Providing unbiased estimates of the status and trends in forest condition for all regions of the U.S.
- Selecting statistical estimators for spatial patterns, trend detection, and ecological modeling.
- Providing a full assessment of the components of variance for all indicators in all regions.

1.3.1.2 Status and Trends of Stress Effects on Ecological Resource Indicators

EMAP-Forests will provide unbiased, regional estimates of the status and trends of indicators of stresses on ecological resources in forests that include land management practices, pollutants, and natural stresses on an annual basis for all ecoregions of the United States.

1.3.1.2.1 Short-term Objectives (1-5 years)

By 1995, EMAP-Forests will resolve the following technical issues:

- Identification of key indicators for monitoring for air pollutant stress and the accuracy needed for these variables.
- Evaluation of the relationship between air pollution and visual symptom indicators of air pollution stress on forest vegetation.
- Selection and testing in a pilot mode key indicators of land use practices and other management stresses on forests.
- Incorporation of forest pest management surveys into annual statistical summaries of forest health.
- Evaluation of important climatic variables and their correlation to forest condition.
- An evaluation of indicators of the accumulation of toxins in foliage and soils.

By 1995, EMAP-Forests will develop an effective process for incorporating stress information into forest health monitoring by:

- Integrating climatic data and air pollution data into all annual statistical summaries.
- Developing a strategy for completing detailed landscape characterization around established field plots to document management stresses.
- Involving FS Forest Pest Management staff in detection level monitoring activities.

By 1995, EMAP-Forests will provide the following products:

- Maps of air quality for regions where forest health monitoring has been implemented.
- Maps of climatic stress in the same regions.
- Maps of other natural stresses in those regions.

1.3.1.2.2 Mid-term Objectives (6-10 years)

By 2000, EMAP-Forests will improve technical capabilities of the program by:

- Field testing inexpensive air pollution monitors at plot sites.
- Developing and testing models for improving the estimation of climatic stresses

at plots from off-frame monitoring locations.
- Providing interpretive assessments for all endpoints in U.S. forests.

1.3.1.2.3 Long-term Objectives (11+ years)

By 2005, EMAP-Forests will demonstrate the effectiveness of the forest health monitoring program by:

- Developing an integrated index of forest stress.
- Identifying regions where excessive air pollution or management stress is associated with poor forest conditions.
- Initiating research projects to further evaluate why certain forest resources are in poor condition.

1.3.1.3 Assessment and Reporting

EMAP-Forests will provide to the Administrator and the public annual statistical summaries and assessments that evaluate the associations between indicators of forest condition and indicators of stress on these ecosystems.

1.3.1.3.1 Short-term Objectives (1-5 years)

By 1995, EMAP-Forests will resolve the following technical issues:

- Development of method for incorporating off-frame indicator data into forest health assessments.
- Development of method for reducing the uncertainty in regional forest condition estimates through the use of other monitoring data such as forest inventory and analysis.

By 1995, EMAP-Forests will improve the ability to provide interpretative assessments by:

- Identifying appropriate areas for program integration (e.g. the development of assessment infrastructure) among the EPA, the FS and other cooperating agencies.
- Obtaining appropriate equipment and analytical tools for assessments.
- Identifying regional forest assessment units to complement the national program.

By 1995, EMAP-Forests will provide the following products:

- An annual statistical summary that includes indicator data from all regions where regional forest health monitoring has been implemented.
- Summaries of all indicator development projects funded by EMAP-Forests.

1.3.1.3.2 Mid-term Objectives (6-10 Years)

By 2000, EMAP-Forests will improve its assessment capabilities by:

- Providing its first interpretative report of forest condition for a region.
- Including landscape level assessments for regions where landscape characterization has been completed.
- Contributing to the integration of data among EMAP resource groups.
- Providing assistance to other countries interested in developing similar programs.
- Integrating forest health monitoring assessments into the EPA regional risk assessment framework.

1.3.1.3.3 Long-term Objectives

By 2005, EMAP-Forests will demonstrate the effectiveness of assessment capabilities by:

- Providing integrated among EMAP resource group interpretative assessments by ecoregion.

- Demonstrating the associations between indicators of forest condition and stress on forested ecosystems.
- Cooperating in the expansion of EMAP to high priority areas (e.g., tropical forests) to address international monitoring issues such as global change.

1.4 ASSESSMENT ENDPOINTS

The EMAP-Forests approach is structured around a suite of assessment endpoints defined for indicators of forest condition. Assessment endpoints are quantitative goals for these indicators (Suter 1990; Messer 1990). The assessment endpoints provide an appropriate basis for structuring a program because they will satisfy the public demand for relevant environmental information. The challenge of EMAP-Forests is to identify indicators that can be combined in a quantitative manner to make overall statements of status and trends in assessment endpoints. Section 3 presents a more complete discussion of indicators and assessment endpoints.

1.5 LEGISLATIVE AND AGENCY MANDATES

The EPA and the FS have received specific directions from Congress to address the effects of air pollution on forests. Title IX of the Clean Air Act amended (1990) states:

"In carrying out subsection (a), the Administrator, in cooperation, where appropriate, with the Under Secretary of Commerce for Oceans and Atmosphere, the Director of the Fish and Wildlife Service, and the Secretary of Agriculture shall conduct a research program to improve understanding of the short-term and long-term causes, effects, and trends of ecosystems damage from air pollutants on ecosystems. Such program shall include the following elements: (1) Identification of regionally representative and critical ecosystems for research. (2) Evaluation of risks to ecosystems exposed to air pollutants, including characterization of the causes and effects of chronic and episodic exposure to air pollutants and determination of the reversibility of those effects. (3) Evaluation of the effects of air pollution on forests, materials, crops, biological diversity, soils, and other terrestrial and aquatic systems exposed to air pollutants."

In 1988, the Forest Ecosystems and Atmospheric Pollution Research Act (Public Law 100-521) explicitly authorized the FS to undertake the necessary monitoring to track long-term trends in the health and productivity of forest ecosystems in the United States:

"The Secretary, acting through the United States Forest Service, shall (a)increase the frequency of forest inventories in matters that related to atmospheric pollution and conduct such surveys as are necessary to monitor long-term trends in the health and productivity of domestic forest ecosystems..."

In addition to these agencies, other agencies have specific mandates regarding the management and protection of forested ecosystems. Examples include the National Park Service, the Bureau of Land Management, and State Forestry agencies. Other agencies such as the Soil Conservation Service and the Fish and Wildlife Service have specific mandates regarding the condition of certain aspects of forested ecosystems.

A representation of the need for coordination among these agencies is given in Figure 1.1. Forest condition at the center of the diagram is impacted by a combination of air pollutant, natural, and management stresses. A multi-agency monitoring program such as forest health monitoring is being designed to monitor the cumulative impact of these stresses on forest ecosystem condition. When forests are found to be in an adverse

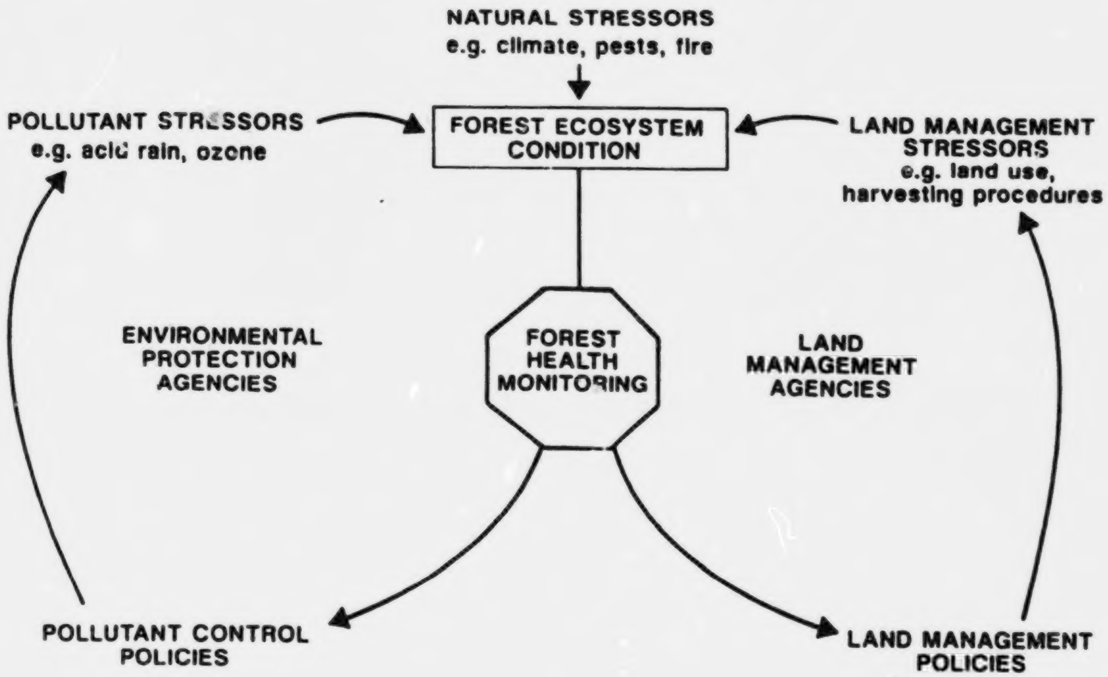

NATURAL STRESSORS
e.g. climate, pests, fire
POLLUTANT STRESSORS
e.g. acid rain, ozone
FOREST ECOSYSTEM CONDITION
LAND MANAGEMENT STRESSORS
e.g. land use, harvesting procedures
ENVIRONMENTAL PROTECTION AGENCIES
FOREST HEALTH MONITORING
LAND MANAGEMENT AGENCIES
POLLUTANT CONTROL POLICIES
LAND MANAGEMENT POLICIES

Figure 1.1. Need for coordination among agencies involved in EMAP Forests.

condition, detailed studies will be implemented to identify the cause. If a linkage to air pollution or other form of pollution is found to exist, then this information can be provided to the EPA policy analysts. If the problem can be attributed to land management actions, then this information could influence land management policies. If natural stress is identified as the cause, then no applicable corrective actions may be required.

1.6 HISTORY

Two important FHM projects were undertaken during the summer of 1990. Prior to discussing these projects, a short history of the development of EMAP-Forests and FS-FHM will be provided.

1.6.1 History of EMAP-Forests

Planning for a program in forests within EMAP began with the appointment of Richard Olsen as the EMAP-Forests Technical Director in July, 1988. Prior to this appointment, Mr. Olsen had served as the Manager of the Western Conifers Research Cooperative in the Forest Response Project (FRP), a research program conducted under the auspices of the National Acid Precipitation

Assessment Program (NAPAP) Task Group V--Terrestrial Effects. The FRP was funded by the FS, EPA, and the National Council of the Paper Industry for Air and Stream Improvement.

Mr. Olsen immediately began an assertive program to develop a national monitoring plan. He organized a series of workshops to identify candidate indicators of forest health and initiated work on a monitoring design. Due to his previous experience in the interagency FRP, he made a special effort to develop EMAP-Forests in cooperation with similar efforts in the FS.

In April 1989, Mr. Olsen was reassigned to a new program and Craig Palmer assumed the role of EMAP-Forests Technical Director while continuing in his position as Quality Assurance Officer for the FRP. The EMAP program focus at this time was the selection of indicators of ecological condition. EMAP-Forests staff conducted a series of workshops resulting in a preliminary set of indicators and prepared a chapter for the overall EMAP indicators report (Hunsaker and Carpenter 1990). Throughout this period, the FRP served as useful tool to foster communication between the EPA and the FS in the development of a possible multi-agency FHM program.

In November 1989, the EMAP program conducted a competition between the resource groups for the funding of FY90 field activities. The EMAP steering committee selected the EMAP-Forests proposal for funding. The focus of this proposal was a field evaluation of forest health indicators in cooperation with proposed FS monitoring activities in New England.

1.6.2 History of FS-FHM

The FS began its development of a forest health monitoring program approximately five years ago. With the development of the Acid Rain National Early Warning System (ARNEWS) forest monitoring project in Canada, momentum grew for the development of a similar program in the United States. A series of pilot studies were undertaken as part of the FRP under a project called the National Vegetation Survey (NVS) directed by Joe Barnard of the Southeast Experiment Station.

One objective of the NVS was to develop techniques to inventory and monitor symptoms of atmospheric pollution-induced stress, damage, and/or death of forest stands and trees. A select group of indicators for determining forest condition was identified in workshops in 1987 and implemented during pilot tests in 1988 and 1989. Visual damage survey plots were established in mixed hardwood forests (128 plots), high elevation spruce fir forests (31 plots), and natural loblolly pine stands in the piedmont (157 plots) and coastal plain (222 plots) regions.

During this time, a committee was formed to develop a long-term forest health monitoring approach for the FS. A multi-tiered process was proposed consisting of three levels with increasingly detailed monitoring. These will be discussed in section 2. This proposal was circulated in the FS in the fall of 1989. Top-level managers within the FS also met with representatives of the New England states to discuss implementation of a forest health monitoring program in 1990. On November 20, 1989, agreement was reached between the FS and the New England states to begin such a program. Shortly thereafter, a regional project manager was appointed (Bob Brooks) and a national FS-FHM coordinator was selected (Joe Barnard).

1.6.3 History of 1990 Field Projects

The period after November 20, 1989 was filled with planning activities within EMAP-Forests and the FS-FHM program. Although both agencies intended to undertake forest health monitoring field activities in 1990, no mechanism existed to ensure that one program could be developed to meet the needs of both agencies. Two separate motivating factors were driving the planning process in each agency. EMAP-Forest staff were preparing a defense of proposed indicators and therefore recommended indicator evaluations on a regional basis. The FS staff were attempting to begin the implementation of a long-term monitoring program and therefore desired to build upon indicators already evaluated in the visual symptom pilot tests of the NVS.

In late March 1990, a meeting was held in Portsmouth, New Hampshire with participants from EMAP-Forests, the FS-FHM national program, and the FS-FHM New England program. At this meeting it was decided that two separate projects be undertaken in 1990. One project would establish long-term monitoring plots using the EMAP grid (described in Section 2) and would include visual symptoms measurements. This project would be championed by the FS with the assistance of state field crews. This effort would be called New England Forest Health Monitoring (NE-FHM). EMAP-Forests staff were to provide assistance in QA and IM.

A second project was proposed for a field evaluation of several additional indicators. EMAP-Forests staff were to take the lead in planning this project but the field work was to be implemented under the direction of the FS. It was suggested that approximately twenty plots be established in New England in northern hardwoods and twenty plots be situated in Loblolly pine stands of Virginia on sites that would not become FHM plots. As a result, this second project was named the 20/20 pilot study. Subsequent workshops resulted in the selection of five indicators for evaluation in the 20/20 study including growth efficiency, visual symptoms, soil productivity, foliar nutrients, and vertical vegetation structure.

Both projects were successfully undertaken during the 1990 field season. In the NE-FHM project, over two hundred plots were established across New England. The percentage of plots established in each forest type closely approximated the relative abundance of the various forest types found in New England. The 20/20 project was also successful in achieving the majority of its objectives. Final reports are currently in preparation for these projects. Present planning efforts are directed towards the expansion of FHM plots to six new states with indicator development activities occurring simultaneously on a subset of these plots.

The success of these projects has provided a strong basis for cooperative efforts in the 1991 field season. If a multi-agency FHM program is developed, it will owe a debt of gratitude to it's origins that were fostered and cultivated in the FRP.

1.7 COORDINATION

Coordination with components within and outside of EMAP is fundamental to the success of the EMAP-Forests strategy. This subsection identifies target groups with which EMAP-Forests must establish a working relationship, explains why coordination with these groups is important, and describes efforts to coordinate specific strategies in FY91.

1.7.1 Coordination Within EMAP Cross-cutting Activities

To support resource monitoring activities, EMAP has developed a number of cross-cutting activities (see Figure 1.2). The activities include air and deposition, landscape characterization, information management, integration and assessment, statistics and

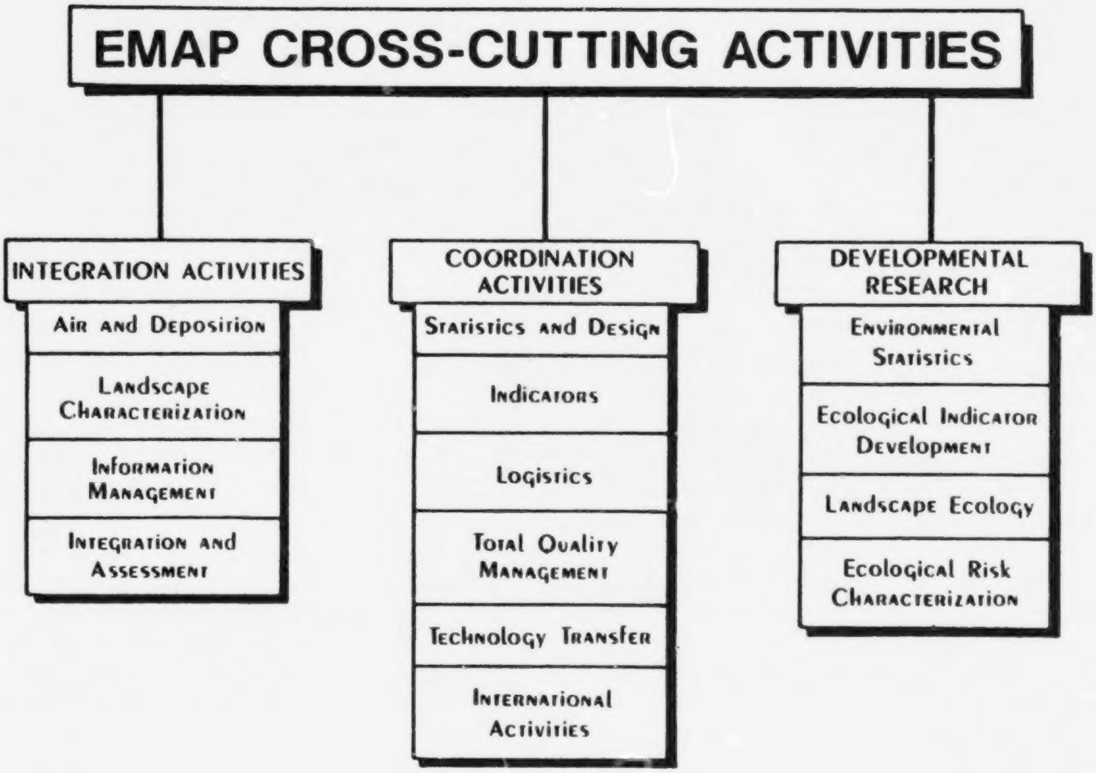

EMAP CROSS-CUTTING ACTIVITIES
INTEGRATION ACTIVITIES
Air and Deposition
Landscape Characterization
Information Management
Integration and Assessment
COORDINATION ACTIVITIES
Statistics and Design
Indicators
Logistics
Total Quality Management
Technology Transfer
International Activities
DEVELOPMENTAL RESEARCH
Environmental Statistics
Ecological Indicator Development
Landscape Ecology
Ecological Risk Characterization

Figure 1.2. EMAP cross-cutting activities.

design, indicators, logistics, TQM, and technology transfer. These groups provide support in areas such as developmental research in environmental statistics, ecological indicator development, landscape ecology, and ecological risk characterization. These cross-cutting activities, each of which is headed by a technical coordinator (TC), enhance overall program uniformity and optimize the use of planning resources.

Cooperation and coordination will prove mutually beneficial to EMAP-Forests and these cross-cutting activities. EMAP-Forests will gain insight from the specialized tasks of each cross-cutting activity. On the other hand, the cross-cutting activities will benefit from the lessons learned by EMAP-Forests, one of the first resource groups to implement field operations. EMAP-Forests can also influence the development of overall EMAP approaches by supporting the development of guidance documents for these cross-cutting activities.

Currently, EMAP-Information Management and EMAP-Quality Assurance have EMAP-wide committees that consist of resource group information managers and QA officers, respectively. EMAP-Information Management also has an EMAP-wide committee of geographic information systems (GIS) analysts that addresses spatial data management, spatial analysis, and reporting issues. EMAP-Forests will encourage the other cross-cutting activities to form similar committees to conduct workshops, review planning documents, develop training procedures, and guide development activities. Additionally, EMAP-Forests has assigned a lead for each cross-cutting activity and then, where possible, located that lead at the same EPA laboratory as the TC for the EMAP cross-cutting activity. For example, the EMAP TCs for design and indicator development are located at the EPA Environmental Research Laboratory at Corvallis, Oregon. EMAP-Forests leads in design and indicator development are located there also, thus enhancing communication and coordination between the groups.

EMAP-Forests personnel will actively participate in the development of both the EMAP-Integration and Assessment and EMAP-Landscape Characterization strategies to assist in ensuring that all needs are being adequately addressed and that efforts are being coordinated. One goal of EMAP is to use integrated assessments to report on environmental health at regional levels. This methodology implies an integrated program that must be well-coordinated among the various components. The development of linkages between various levels of information is paramount for success in this integration process. The efforts of EMAP-Integration and Assessment and EMAP-Landscape Characterization are central to how these linkages are established.

During 1991, EMAP-Forests staff will coordinate a number of specific efforts with EMAP cross-cutting activities. For example, EMAP-Forests staff will serve on the Clean Air Act Committee with EMAP-Air and Deposition staff. Joint pilot activities will be explored with EMAP-Landscape Characterization. A pilot project on the global positioning system will be conducted with the EMAP-Information Management staff. EMAP-Forests staff will also work with the design TC to evaluate monitoring design alternatives, the indicator development TC to develop detailed objectives for regional demonstration studies, and the logistics TC to explore the possibility of multi-agency regional logistics centers. In addition, EMAP-Forests personnel will participate in the development of QA guidance documents for terrestrial ecosystems with the EMAP QA Officer. EMAP-Forests will also participate in an EMAP-wide user needs analysis process that will identify informational, hardware/software, staffing, and data needs of the various program components.

1.7.2 Coordination among Resource Groups

Coordination among resource groups is needed to ensure that all ecosystems are monitored and to prevent duplication of efforts. EMAP planners recognize that the current EMAP approach to dividing the landscape is relatively arbitrary and could be accomplished by many different approaches. An advantage of the EMAP divisions is that they encourage cooperation with other agencies with specific mandates such as the FS (forests), the U.S. Fish and Wildlife Service (wetlands), or the USDA (agricultural lands). Most importantly, these resource groups are interrelated in nature; therefore they should be interrelated conceptually. For example, surface water quality is affected by forest management practices, and wildlife are affected by activities across the landscape. For this reason, it is important that monitoring be developed in such a way that the various resource groups can be integrated.

Coordination among resource groups offers other advantages. Similar indicators are often selected by different resource groups. For example, soils have been selected as an indicator by all terrestrial resource groups. Soil scientists who are chosen as indicator leads can assist and coordinate soil indicator development activities across resource groups. This approach not only saves money, but it also fosters the integration of data collected by the various groups. Lessons learned by one resource group can be used by another.

EMAP structure also encourages coordination among some resource groups. All terrestrial resource groups are under the direction of one associate director. Coordination is fostered through workshops, biweekly conference calls, coordinated peer reviews, and the sharing of some indicator leads. Unfortunately, this coordination has not extended very well to other resource groups. Recognizing the need for better coordination between all resource groups, all of the EMAP TDs meet on a quarterly basis and participate in biweekly conference calls.

A number of specific coordination issues need to be resolved this year. For example, the status of the pinion juniper is in question because it fits the definition of both forests and arid lands resource groups. EMAP-Forests and EMAP-Agroecosystems need to resolve the status of woodlots. In addition, surface water nitrate is one of the proposed indicators for EMAP-Forests, and it is also one of the measurements made by EMAP-Surface Waters. However, EMAP-Surface Waters may not sample a surface water on the same watershed associated with forest monitoring even if they sample in the same hexagon. To require them to do so would bias their sampling scheme. Forested wetlands is another unresolved area. This year, EMAP-Forests staff will need to work in conjunction with the EMAP-Wetlands group to develop protocols for sampling wet or submerged soils. EMAP-Near Coastal is interested in land uses in watersheds impacting near coastal ecosystems. The characterization of landscapes will need to be coordinated with EMAP-Forests efforts in landscape characterization.

1.7.3 Coordination With the U.S. Forest Service

The importance of coordinating with the FS has been a theme of this plan. This coordination focuses on the FS-FHM but also includes coordination with regional groups responsible for monitoring. Ultimately, the goal is to develop a truly multi-agency program with common goals, objectives, and approaches that meet the needs of all agencies.

During the past year, efforts have been undertaken to encourage the development of a multi-agency program. National planning meetings have been held on a quarterly basis to develop a multi-agency monitoring strategy. At these meetings, special committees have been organized to address the issues specifically. A representative of each of these committees participates in a weekly conference call to review progress in planning or field activities. On occasion, these committees have held special meetings to resolve issues. For example, the design committee has held two national planning meetings and has invited many of the best statisticians from the FS and the EPA to attend.

During FY91, the principal coordination objective will be to develop a multi-agency forest health monitoring plan. This EMAP-Forests strategy document is the first step in that direction. Additional workshops will be required and detailed studies will need to be completed to resolve many of the issues presented in this plan. An important component of this year's efforts will be an outreach program. It will include individuals from all regions of the country in the national planning effort.

1.7.4 Coordination Within the EPA

A number of divisions in the EPA have expressed interest in EMAP-Forests, including the regional offices, the program offices, and other research programs such as the global climate change program and the ozone program. EMAP-Forests has not adequately addressed the needs of these clients. During FY91, EMAP-Forests will renew its efforts to better inform and coordinate with these groups. Regional liaison individuals will be identified and contacted. Program offices will be contacted, and individuals with interest in the ecological condition of forests will be identified. Principal scientists who work at the EPA on a program that has a forest component will also be contacted. All of these individuals will be sent information packets on EMAP-Forests. Client-need surveys, which will include written and oral interviews will be conducted. Invitations will be sent to attend field tours or to participate in planning meetings. The EMAP Monitor (a newsletter) and EMAP task descriptors will be sent to individuals who express an interest in EMAP-Forests. A list of EMAP-Forests publications and a request sheet will be sent to them on a periodic basis.

1.7.5 Coordination With Other State and Federal Agencies

In addition to the FS, other government agencies have a responsibility for the management of forest land. These agencies include state forestry agencies, the BLM, and the NPS. The support of all of these agencies is needed for a successful nationwide forest health monitoring effort. The permission of these agencies will be needed for access to the lands they manage. Most states, management agencies, and the NPS have already initiated forest health monitoring activities. As a result, forest scientists in these agencies have developed expertise that would enhance the planning and implementation of the FHM effort. These scientists have pointed out that they can benefit by ensuring that comparable data are collected to allow them to evaluate their results in a regional perspective.

Coordination efforts with state forestry agencies began in 1990 in New England through the implementation of forest health monitoring with state crews. The FS has worked well with state agencies and has led the effort to coordinate with the states. The current national strategy is to implement FHM on a state-by-state basis.

This year other agencies must be included in the national planning effort. They can contribute to the effort and will more readily cooperate with the implementation of monitoring on their forest lands if they have had some input during the planning process. Forest health monitoring will expand to the western United States in 1992 and agencies with responsibility in this region must be contacted. Representatives of the agencies will be invited to attend national planning meetings and participate in workshops to plan pilot activities for their regions.

1.7.6 Coordination With Research Organizations

To be successful, FHM must be founded on sound scientific principles. Research scientists at universities and state and federal research centers can assist in the development of the program in many ways. During the planning process, researchers can assist in the identification and selection of candidate indicators and in the development of a conceptual framework for interpreting the relationships among the indicators. Current research sites offer many opportunities for evaluating new indicators. Examples include the National Science Foundation- funded Long-term Ecological Research (LTER) sites, the Man in the Biosphere reserves, and the National Energy Parks.

Coordination can be accomplished if scientists are informed of developments in the planning and implementation of FHM. For example, a presentation on forest health monitoring was made at the 1990 fall LTER meeting and at the International Ecological Indicator Symposium. A synthesis of the EMAP-Forests indicator strategy has been submitted to a scientific journal.

During this coming year, representatives of the scientific community will evaluate and peer-review all EMAP-Forests plans and reports. Indicator development proposals will be solicited and funded for the detection level of monitoring. In future years, scientists will be encouraged to participate in evaluation and research monitoring activities as well.

1.7.7 Coordination With Forest Health Monitoring Activities in Other Countries

Other countries, including Canada (the Acid Rain National Early Warning System) and many European countries, have ongoing forest health monitoring activities. Coordination with these countries would enhance the comparability of data and encourage the sharing of lessons learned during the implementation of forest health monitoring programs. Other cooperative efforts could be initiated. These include sample exchange programs, development of reference materials, and international workshops on forest health monitoring.

This year, EMAP-Forests staff will participate in forest health monitoring workshops in Canada and Europe. EMAP-Forests staff will also participate in the 4th International Quality Assurance Workshop to address terrestrial QA issues. It is hoped that international experts will participate as peer reviewers of EMAP-Forests plans.

2. APPROACH AND RATIONALE

Section 2 provides an overview of the EMAP approach with an emphasis on the conceptual and technical components as applied to EMAP-Forests. The rest of the sections fill in the details of the strategy plan.

2.1 RESEARCH DESIGN

2.1.1 Overview of the EMAP-Forests Research Approach

An understanding of EMAP'S four-tiered approach is important to the presentation of the EMAP-Forests strategy for meeting the program objectives. In the overall EMAP approach, a tier is a level and type of activity related to monitoring and assessing ecological condition. Figure 2.1 outlines the four-tiered approach to monitoring activities (Anonymous 1990). Although most of this document discusses activities at the Tier 1 and Tier 2 levels, Tiers 3 and 4 are also important components of long-term monitoring.

Tier 1, the broadest level, focuses on landscape characterization, the estimation of a resource's extent and geographical distribution. This may include the pattern of use on the landscape. Techniques such as remote-sensing and the geographic information system (GIS) are important at this level. For EMAP-Forests, characterization of the forest resource includes determination of the extent and type of forests on a regional basis.

Tier 2 activities are intended to allow estimation of status and trends in resource condition. A suite of chemical, physical, and biological measurements are obtained from a subset of Tier 1 sites and this information is aggregated to make statements about the status and trends of the resource on a regional basis. Section 3 presents a more detailed discussion about the suite of measurements to be used in EMAP-Forests.

Tier 1 and 2 activities will allow the successful completion of the primary EMAP objectives and will be the priority in early funding. However, additional information needs will require the activities of Tiers 3 and 4. These complementary levels will provide information about status, trends, and diagnostics for more specific subpopulations of interest and provide the link to ecological research.

Tier 3 has two primary functions. First, it is to determine whether or not the perceived conditions warrant additional evaluation, and then it is to provide the diagnosis of a problem and the basis for deciding what actions should be taken. This activity may include intensifying the sampling grid in a specific area, allowing more concentrated data collection to evaluate a specific problem.

Tier 4 is essentially the research component of EMAP which supports the monitoring activities of Tiers 2 and 3. The first phase of Tier 4 focuses on the generation of an ecological conceptual framework which will be used to implement, test, and refine monitoring indicators from Tiers 2 and 3. Tier 4's second phase includes the use of ecosystem process studies to evaluate experimentally whether or not the monitoring indicators are adequately reflecting the actual condition of the ecosystem.

Because EMAP-Forests is currently working with the USDA Forest Service (FS) to develop a multi-agency forest health monitoring (FHM) program, it is important to outline briefly the FS's approach to forest health monitoring.

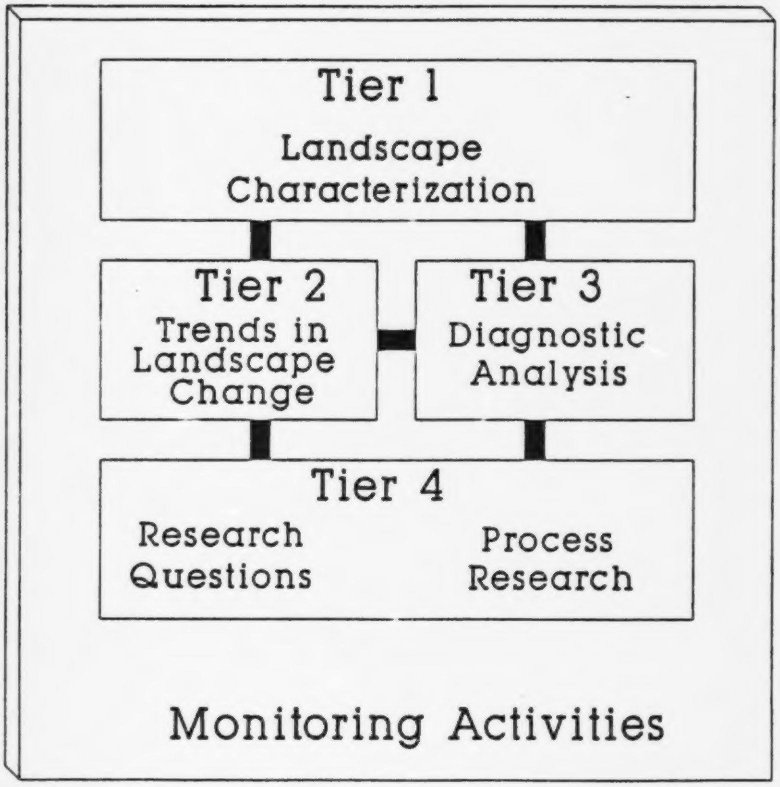

Tier 1
Landscape Characterization
Tier 2
Trends in Landscape Change
Tier 3
Diagnostic Analysis
Tier 4
Research Questions
Process Research
Monitoring Activities

Figure 2.1. EPA EMAP tier outline.

2.1.2 Overview of the Forest Service Research Approach

Over the past five years, the FS has been developing a program for forest health monitoring (FS-FHM) (USDA Forest Service 1989). The FS-FHM program has a three-tiered structure, with each successive tier representing an increased level of detail in the monitoring program.

Detection or "routine" monitoring is the most extensive tier and will be based on a network of permanent plots including the forest inventory and analysis (FIA) plots and other permanent plots maintained by the FS. Additional permanent plots will be used to ensure representation of all forest lands. A subset of "sentinel plots" will be chosen from the geographically-based network of permanent plots and will be used to collect a greater amount of information than from regular FIA plots. Information from routine pest surveys distributed across U.S. forests will be collected by the FS Forest Pest Management (FPM) program and by state agencies. These and other specifically-focused monitoring activities will be linked with the sentinel plot network. It is this monitoring level that will be the primary linkage to EMAP-Forests.

The second tier is evaluation or "ad hoc" monitoring. This level is initiated in response to detection monitoring results. When an area or problem of concern is identified by detection results, specific evaluation needs will be determined and activities such as additional surveys, site- or area-specific evaluations and more detailed monitoring will be initiated.

Research or "investigative" monitoring is the third tier. Sites representing key forest ecosystems throughout the U.S. where both special and ongoing long-term studies are conducted will provide detailed information on all components of the forest ecosystem. This level of monitoring provides data to better understand causal relationships and predict rates of change in forest condition. Examples of research monitoring are the Coweeta and Hubbard Brook research sites. Participating in research monitoring are FS Experiment Stations and universities.

Fortunately, it is evident that the EMAP tier structure is very similar to the FS tier structure. This coincidence will encourage the development of a multi-agency program. A proposed tier structure for coordination by both agencies is presented in Table 2.1.

2.1.3 Overview of EMAP Design

To meet the overall EMAP objectives, EMAP-Statistics and Design has developed the following design criteria:

- Estimate, with known uncertainty, the health and status of any regionally defined resource.

- Describe baseline data allowing rigorous description of trends in health and status of regionally defined resources.

- Identify associations among characteristics both within and among resources to establish possible causes of changed condition.

- Quickly respond to new issues and questions.

Important requirements and features of the design include:

- Explicit definition of target populations and their sampling units.

- Explicit definition of a frame for listing or otherwise representing all the potential sampling units within each target population.

- Use of probability samples on well-defined sampling frames to estimate population characteristics rigorously through randomization and use of probability methods for sample unit selection.

- Flexibility to accommodate a variety of resource types and a variety of problems, some of which have not yet been specified.

- A hierarchical structure permitting sampling at a coarser or finer level of resolution than the general grid density, giving flexibility at global, national, regional or local scales.

- An ability to focus on subpopulations of potentially greater interest (e.g. specific types of trees rather than all trees).

- An ability to quantify statistical uncertainty and sources of statistical variability for populations and subpopulations of interest.

The EMAP-Forests proposed design strategy (see sections 4 and 5) is based upon the overall EMAP design. A permanent

Table 2.1. A comparison of characteristics of the phases of monitoring (Adapted from Figure 3 in Riitters et al. 1988).

	Monitoring phase		
EPA-EMAP Name -> FS-FHM Name ->	Tier 1 & 2 Detection	Tier 3 Evaluation	Tier 4 Research
Characteristic			
Persistence	long-term	short-term	short- or long-term
Frequency of protocol changes	seldom	frequent	often
Spatial coverage	extensive intensive	extensive or intensive	extensive or intensive
Represents	forests	forest issues	mechanisms
Frequency of analyses	continuous	as needed	as needed
Focus of spatial analyses	extrapolation over regions	interpolation within regions	both
Focus of temporal analyses	historical and current	current	current and future
Cause-effect inferences	correlation only	possible	required
Number of parameters	few	a few more	many
Specificity	integrative, non-specific	diagnostic	highly specific
Auxiliary data needed	historical trends	current	future trends

national sampling framework has been proposed that consists of a hexagonal plate containing a triangular grid of approximately 12,600 points placed randomly across the coterminous United States (see Figure 2.2), Alaska, and Hawaii. A 40 km^2 hexagon around each point may be characterized at the landscape level using remote-sensing and geographic information service (GIS) capabilities, aerial photography, and existing landscape information data bases (see Figure 2.3). These data could be updated at approximately 10-year periods.

The 40 km^2 hexagons describe an area that is one-sixteenth of the area of the United States. They provide the basis for regional landscape characterization estimates and the

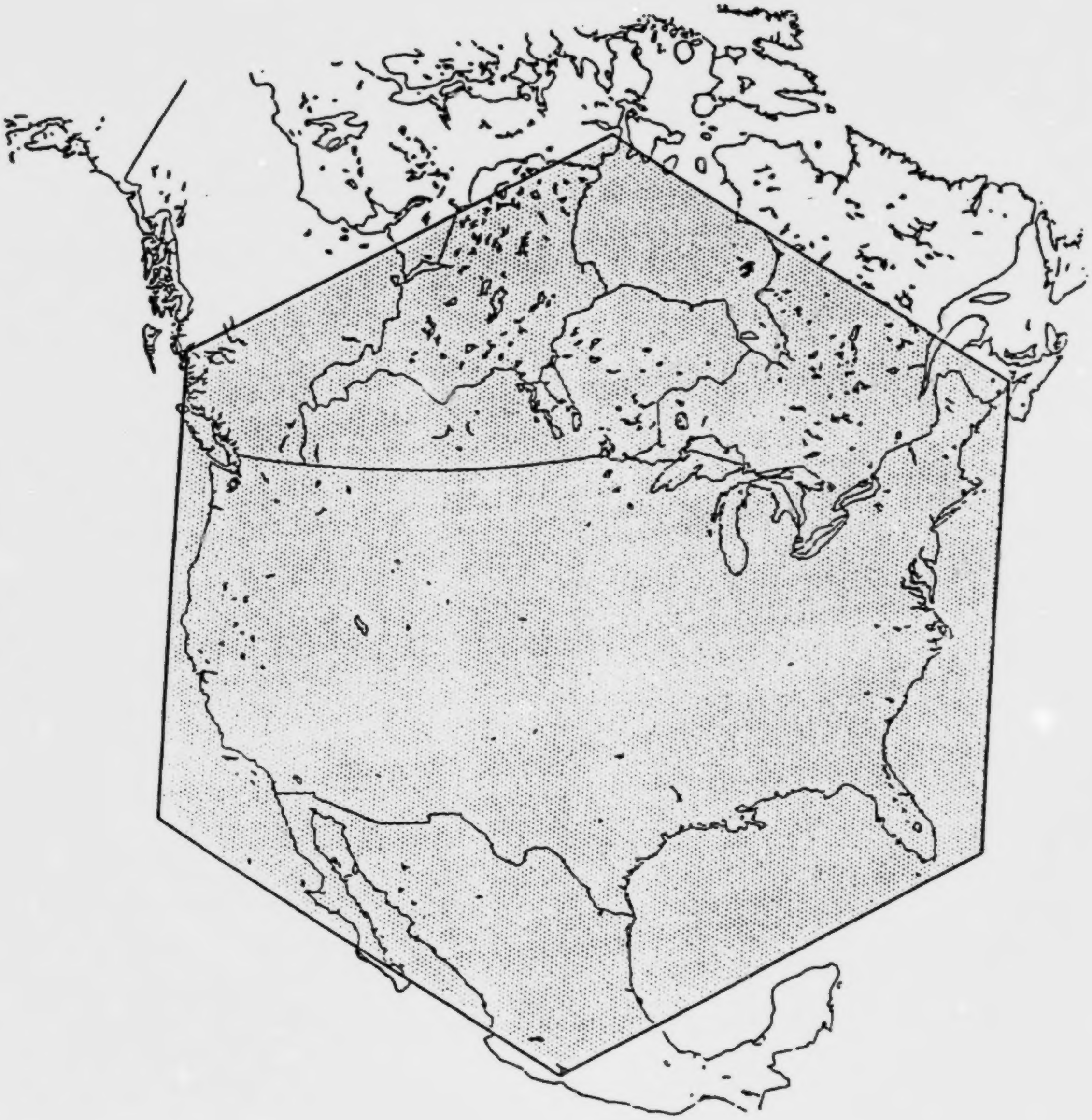


Figure 2.2. The baseline grid (not randomized) for North America containing about 12,6000 points in the conterminous United States. Spacing between points is about 27 kilometers.

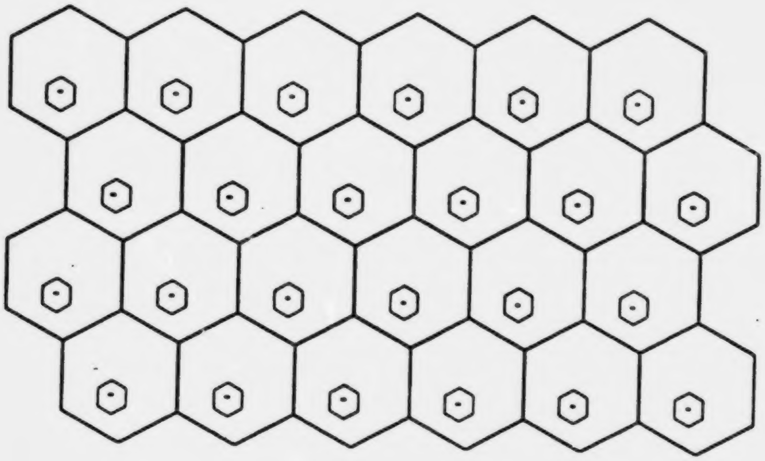


Figure 2.3. The landscape characterization hexagons are 1/16th of the total area and centered on the sampling points. The randomly positioned sampling grid occupies a common but randomly selected position in each of the base tessellation hexagons.

changes in resource characterization over time. A Tier 1 sample consists of the resource units for any explicitly defined subpopulation contained within the 40 km^2 hexagons. Using Tier 1 data, classification and further subpopulation development can be done. Any ecological resource in the landscape is sampled according to strict protocols in proportion to its abundance and frequency of occurrence so that the resource sample reflects the true characteristics of the resource.

The triangular nature of the grid points also allows the increase or decrease of the grid density, according to the sampling requirements of specific resources. Figure 2.4 illustrates a three-, four- and seven-fold increase in grid density. Note that the baseline grid (large dots) can be distinguished within the denser grids. The flexibility of this design will allow sample selection at a resolution useable by individual states, if desired.

Another important aspect of the overall EMAP approach is the temporal and spatial interpenetrating design of site characterization and field sampling. Although the sampling grid consists of 12,6000 points distributed across the coterminous United States, only one-fourth of these points will be considered each year; a subset of these will actually be sampled. A four-year cycle will be followed during which all 12,600 grid points will be considered. At the beginning of the second four-year cycle, the points from the first year of sampling will be revisited. Sections 4 and 5 present more detailed discussions about the EMAP-Forests and FHM designs.

2.2 EMAP CONCEPTUAL FRAMEWORK

2.2.1 The EMAP Assessment Framework within EPA's Office of Research and Development (ORD) is one of six elements of the Ecological Risk Assessment Program (Figure 2.5). EMAP focuses attention on important issues of environmental regulation

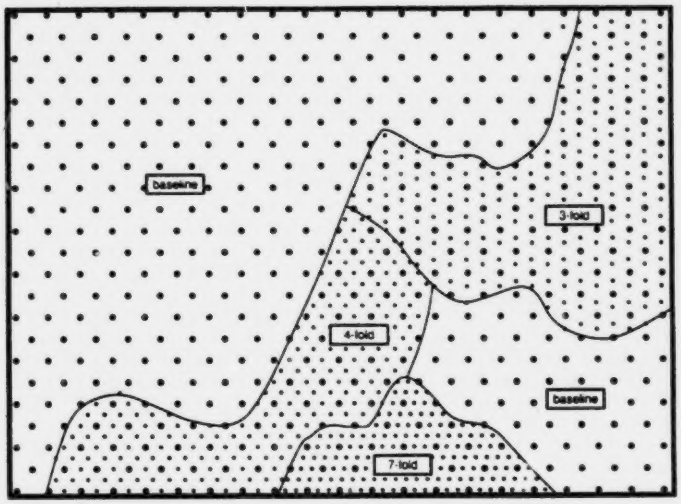

baseline
3-fold
4-fold
baseline
7-fold

Figure 2.4. Enhancement factors for increasing the base grid density. Enhancement will be made only in the sample grid.

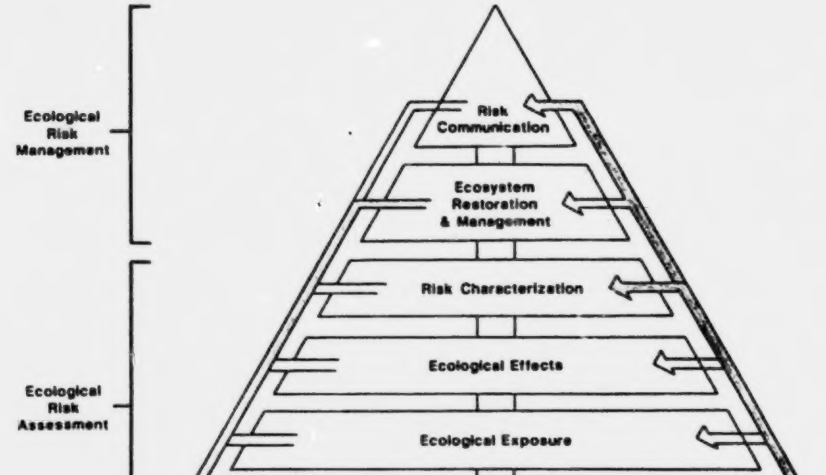

Ecological Risk Management
Ecological Risk Assessment
Risk Communication
Ecosystem Restoration & Management
Risk Characterization
Ecological Effects
Ecological Exposure
Environmental Monitoring & Assessment Program

Figure 2.5. EMAP provides a foundation for the ORD's Ecological Risk Assessment Program. Principal interactions of EMAP with other elements are shaded. (From EPA 1990)

and management by characterizing ecological risk and communicating this information to the Agency Administrator. It also tracks the responses of ecosystems to actions taken to mitigate ecological effects or to reduce risk. To achieve these goals, EMAP uses a flexible, multi-tiered, and regional monitoring design that emphasizes the assessment of indicators of large-scale and long-term ecological effects in relation to indicators of anthropogenic and natural stresses.

In the EMAP risk assessment framework, three broad categories of indicators (response, exposure-habitat, and stressor; see Section 3) are related as shown by the example in Figure 2.6. EMAP relies on response indicators to describe ecological condition. Statistical associations among the values of response indicators and those of exposure, habitat, and stressor indicators, coupled with knowledge about plausible processes and effects mechanisms, will be used to identify possible reasons for poor or changing ecological condition (Messer 1990).

The assessment strategy (see Section 7) and the indicator development strategy (see Section 3) use indicators to link measurements to environmental values. A top-down approach starts by defining the environmental values of concern to society. These values are then represented by assessment endpoints which are "formal expressions of the actual environmental value that is to be protected" (Suter 1990). In EMAP, assessment endpoints are defined, for example, as "proportions of sites subnominal with respect to particular response indicators within a region" (Messer 1990). Definition of these assessment endpoints leads to identification of the needed indicators and thus measurements.

For statistical assessments, EMAP utilizes a statistically based sampling design (see Section 4) that provides unbiased estimates of indicators, with known confidence limits for well defined regional populations. The extent of populations, the proportions of sites which have specified response indicator values, the associations among indicators, and the trends in extent, proportions, and associations can be estimated by this design (see Section 6).

Some trade-offs between ecological and policy relevance are required for interpretive assessments. Keyed to indicators and endpoints, the EMAP approach is somewhere between the extremes of intensively monitoring the environment (to fully explain forest condition) and intensively monitoring the society (to fully assess social perceptions of condition).

Indicators are made to represent key processes and to relate to key values and perceptions about the forest. This strategy does not typically permit causal inferences to be made at the process level and does not necessarily address all of the processes that interact to determine forest status and trends.

For interpretive assessments, monitoring data augmented by knowledge of plausible causes and mechanisms permits analysis of correlations or coincidences of indicator values in space and time (Messer 1990). These analyses can satisfy two of the four criteria suggested by the NRC (1989) for inferring causality in forest environmental assessments. That is, a particular cause-effect hypothesis can be addressed by measures of correlation (consistency and strength) and by measures of temporality (of cause and effect). EMAP cannot address the NRC criteria of responsiveness, or mechanism of effect. The weight of evidence obtained by monitoring data may be strong enough to implicate or clarify certain causal hypotheses, but additional data will usually be required to fully test those hypotheses.

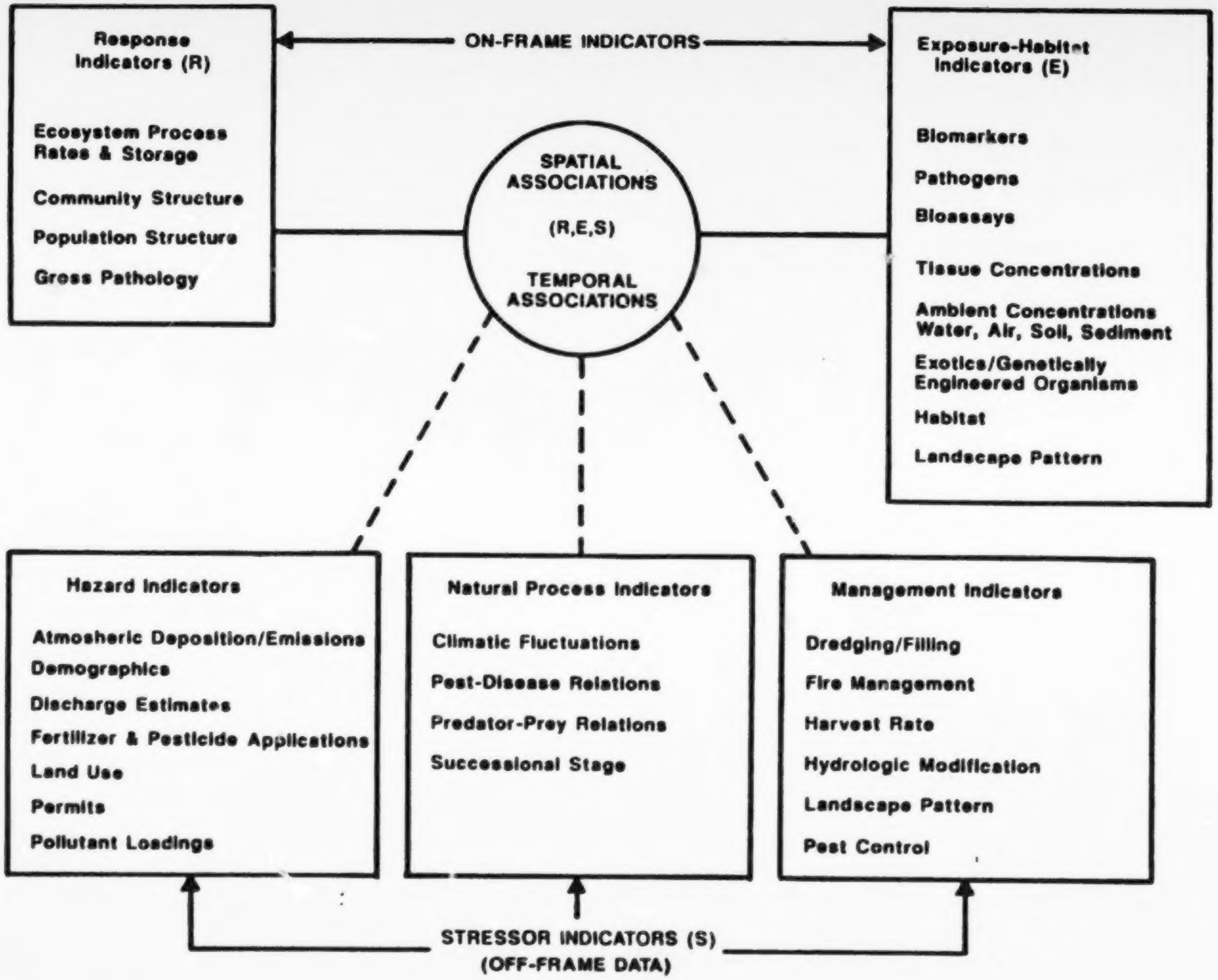

Response Indicators (R)
Ecosystem Process Rates & Storage
Community Structure
Population Structure
Gross Pathology
ON-FRAME INDICATORS
Exposure-Habitat Indicators (E)
Biomarkers
Pathogens
Bioassays
Tissue Concentrations
Ambient Concentrations Water, Air, Soil, Sediment
Exotics/Genetically Engineered Organisms
Habitat
Landscape Pattern
SPATIAL ASSOCIATIONS
(R,E,S)
TEMPORAL ASSOCIATIONS
Hazard Indicators
Atmosheric Deposition/Emissions
Demographics
Discharge Estimates
Fertilizer & Pesticide Applications
Land Use
Permits
Pollutant Loadings
Natural Process Indicators
Climatic Fluctuations
Pest-Disease Relations
Predator-Prey Relations
Successional Stage
Management Indicators
Dredging/Filling
Fire Management
Harvest Rate
Hydrologic Modification
Landscape Pattern
Pest Control
STRESSOR INDICATORS (S)
(OFF-FRAME DATA)

Figure 2.6. The EMAP risk assessment framework.

Some limitations arise as a result of imperfect scientific understanding of forests and of regional interactions between forest condition and environmental stresses. Forests exhibit complex behavior because they are subject to a variety of ubiquitous and variable stresses from natural and anthropogenic sources (Smith 1981, 1984). The complexity is manifested in, for example, interactions among stressors, development of diversity, biological mimicking of symptoms (Treshow 1984), and compensation for stress-induced effects. Changes in forests may be slow, rare, and subtle (Strayer et al. 1986). These difficulties and a traditional scientific focus upon fine-scale processes have prevented any meaningful regional definition of normal spatial and temporal patterns and trends. Nevertheless, "...knowledge of the structure and physiology of forests and trees is now sufficient to develop a basis for detecting disruption or disturbance from a variety of causes" (NRC 1989).

EMAP is designed to provide information to those concerned with regional and national environmental quality (Messer 1990). These individuals do not base their decisions on the actions of individual polluters or resource managers, but, rather, strive to target environmental protection efforts in the most effective way to ensure overall regional or national environmental quality. Because geographic and time scales are related (O'Neill et al. 1986), EMAP is designed to focus on long-term (i.e., decades to centuries) regional phenomena.

The focus of analyses on assessment endpoints means that the apparent condition of each sampled site has to be classified as "good" or "poor" in terms of the observed values of the response indicators. Whether developed from policy or scientific considerations, the classifications are one interpretation and will always be partly subjective. In EMAP, the inevitable subjectivity of interpretations is approached by emphasizing agreement on the data and indicators, and by presenting monitoring results in such a way that alternate interpretations can be made.

Any regional sample is expected to reflect a wide range of condition at a given time; even when conditions are "normal" everywhere, a certain proportion of sites may be in apparently "poor" condition because of normal stresses. In this circumstance, changes in the regional population distributions of indicators would be appropriate measures of change. Yet another issue is that not all indicators will necessarily give the same signal of condition at the same site if they gauge different environmental values or aspects of condition. Normalization of indicator values, covariance-type analyses, and analyses of aggregates of indicators are three possible ways to overcome these difficulties (see Sections 3 and 7).

The monitoring strategy is multi-tiered in the sense that it includes both broad-scale, integrative approaches and finer-scale, specific approaches (Table 2.1). As noted previously, EMAP's Tiers 1 and 2 provide for routine regional-scale monitoring. Tier 1 is concerned mainly with resource characterization and estimation of indicators of stresses and condition over landscape-scale (e.g., 40 sq. km.) sampling units. Tier 2 emphasizes ground-based measurement of indicators on much smaller (e.g., 1 ha.) statistically representative sites. Tier 3 is designed to permit more intensive sampling of more specific indicators in response to conditions observed in Tiers 1 and 2. Tier 4 refers mainly to very intensive site-specific monitoring of a few locations to answer research-oriented questions about forest conditions, and how to monitor and interpret them.

Tiers 3 and 4 are the primary opportunities to bring existing long-term ecological monitoring sites into the picture. These sites can be used for reference sites for continuous monitoring of indicators, or as a framework for doing retrospective analyses of certain measurements and indicators. Incorporating existing sites into the probabilistic Tier 1 and 2 sample designs is not simple but may be possible (e.g., Overton 1990). A critical issue in how to associate an existing site with the probabalistic sample is to determine what portion of the sample frame that the existing site represents. It is also important that many improvements to EMAP's initial design will come from researchers that study ecological processes at these existing sites.

Cross-tier linkages are an important element of the EMAP monitoring design. Successful linkage requires conceptual connections across spatial and temporal scales, and between integrative and specific models of forest processes. The issues of linkage can be best resolved by considering all tiers when planning any one tier, that is, by explicitly recognizing a hierarchical framework. A practical concern is the decision criteria to initiate Tier 3 and Tier 4. Some criteria may be termed "external", for example specific legislation or meritorious scientific hypotheses. "Internal" or data-based criteria are needed to document the planned responses to information generated by Tier 1 and Tier 2 monitoring.

Another important linkage is between the ecosystem types recognized by EMAP (e.g., forests, wetlands, and arid lands). Resource Groups corresponding to ecosystem types were set up originally to facilitate cooperation with other Federal Agencies (e.g., USDA FS, USDA ARS, USDI BLM) that address these different resource types. Common issues were then addressed by EMAP-wide groups (e.g., network design, quality assurance, information management, and logistics). An overall Integration and Assessment group was set up to facilitate cross-ecosystem communication and coordination, and to prepare multiple-ecosystem assessments. In an example of this approach, the forest group is set up as a module (Figure 2.7) that is linked to other resource modules thorugh Tier 1 monitoring, information management, and assessment activities (Figure 2.8). Every module is supported by EMAP-wide projects in quality assurance, remote sensing, logistics, geographic information systems, and statistics (Figure 2.9).

Other approaches to integration are certainly possible. In response to early reviews, EMAP has given increasing attention to the possibility of achieving closer integration and more holistic assessments by erasing some of the definitional or programmatic distinctions among ecosystems. In this approach, ecologically-relevant landscape-level sample units defined at Tier 1 are sampled in a more coordinated fashion by the different ecosystem groups at Tier 2. This requires a more expansive view of ecological condition by each ecosystem group and possibly modification of the statistical designs described in this strategy. To help test this possibility, EMAP-Forests has been developing certain indicators in cooperation with EMAP-Arid Lands and EMAP-Agroecosystems resource groups and is exploring assessment approaches through the EMAP-wide Integration and Assessment Group. This approach is programmatically more difficult because it requires coordination among a number of Agencies that cooperate with EMAP.

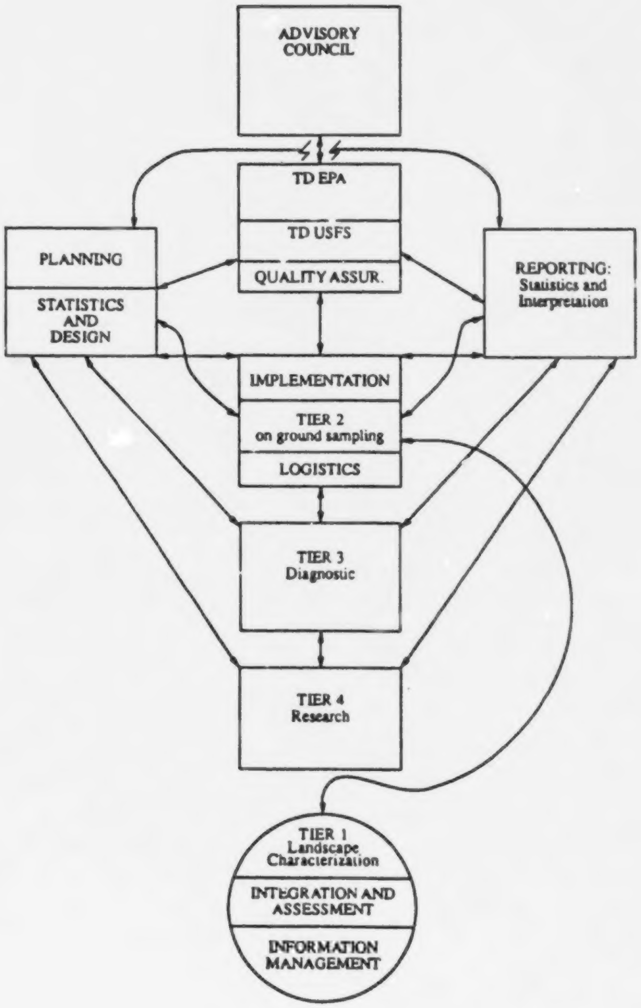

ADVISORY COUNCIL
TD EPA
TD USFS
QUALITY ASSUR.
PLANNING
STATISTICS AND DESIGN
REPORTING: Statistics and Interpretation
IMPLEMENTATION
TIER 2 on ground sampling
LOGISTICS
TIER 3 Diagnostic
TIER 4 Research
TIER 1 Landscape Characterization
INTEGRATION AND ASSESSMENT
INFORMATION MANAGEMENT

Figure 2.7. Structure of EMAP-Forests resource group as a module.

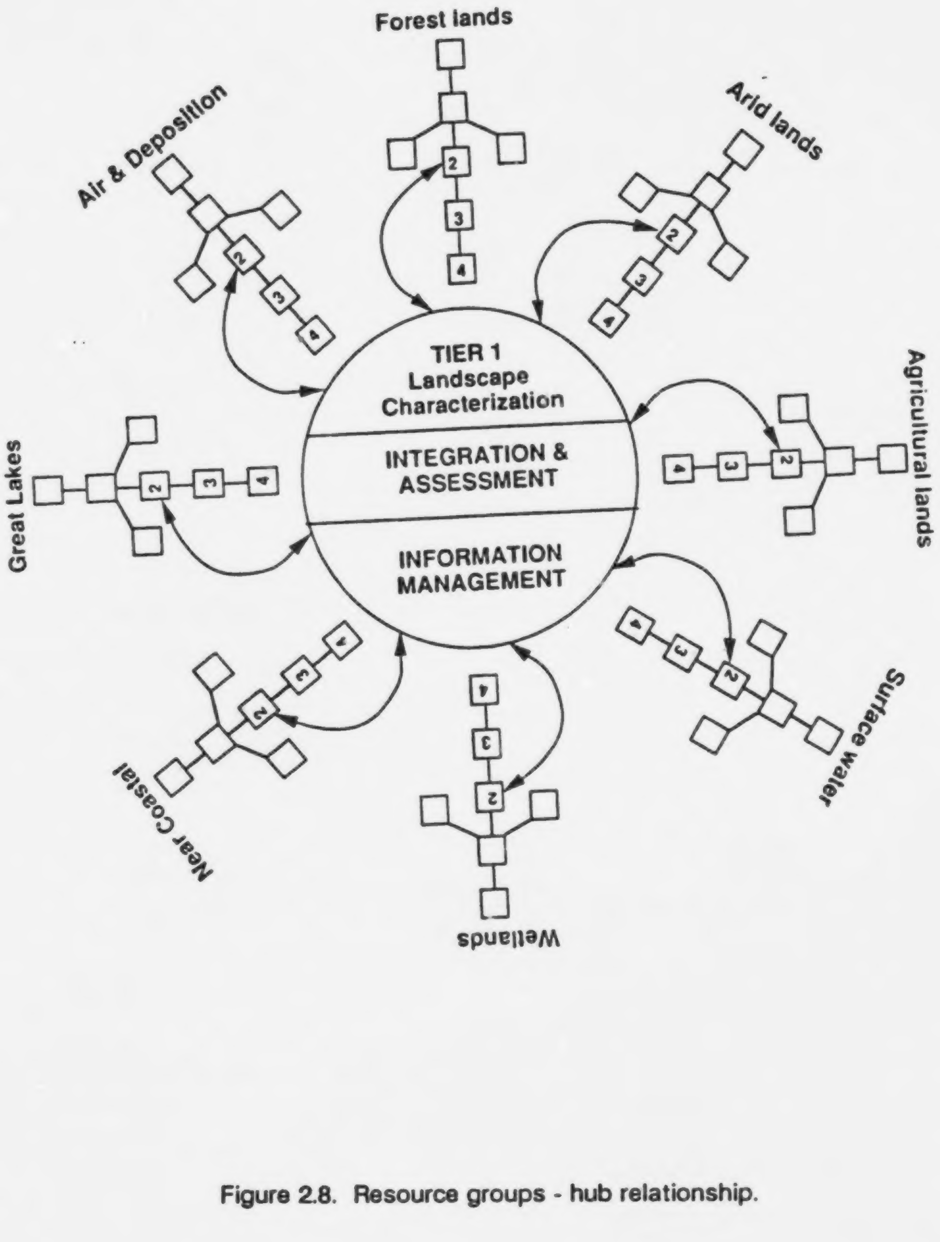
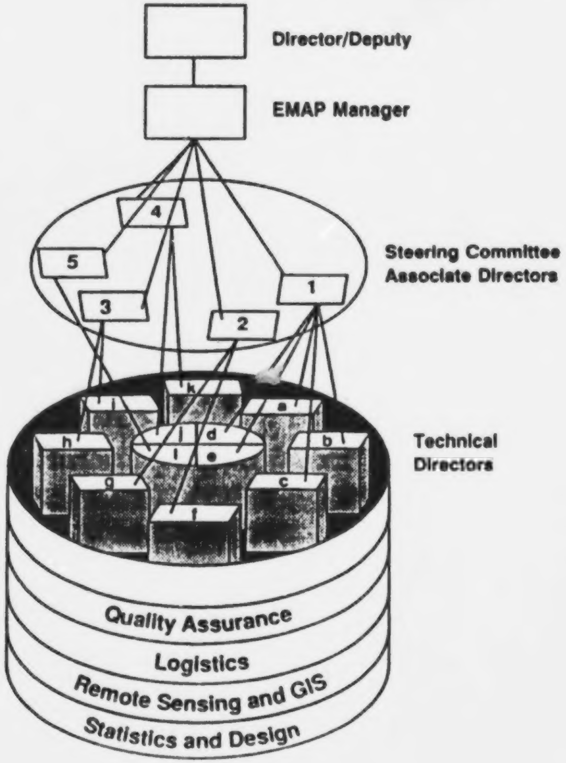

Forest lands
Arid lands
Agricultural lands
Surface water
Wetlands
Near Coastal
Great Lakes
Air & Deposition
TIER 1
Landscape
Characterization
INTEGRATION &
ASSESSMENT
INFORMATION
MANAGEMENT
2
3
4

Figure 2.8. Resource groups - hub relationship.

EMAP
Conceptual Organization Showing Terrestrial Resource Groups in Context


Director/Deputy
EMAP Manager
Steering Committee
Associate Directors
Technical
Directors
1
2
3
4
5
a
b
c
d
e
f
g
h
i
j
k
l
Quality Assurance
Logistics
Remote Sensing and GIS
Statistics and Design

1. Group 1
   a. Forest Lands
   b. Arid Lands
   c. Agricultural Lands
   d. Landscape Characterization
   e. Information Management
      Remote Sensing and GIS
2. Group 2
   f. Surface Waters
   g. Wetlands
      Statistics and Design
3. Group 3
   h. Near Coastal
   i. Great Lakes
4. Group 4
   j. Integration & Assessment
   k. Air & Deposition
5. Group 5
   l. Headquarters Administration
      Logistics

Figure 2.9. EMAP conceptual organization showing terrestrial resource groups in context.

2.2.2 Towards an EMAP-Forests Assessment Paradigm

> The wind was flapping a temple flag, and two monks were having an argument about it. One said the flag was moving, the other that the wind was moving; and they could come to no agreement on the matter. They argued back and forth. Eno the Patriarch said, "It is not that the wind is moving; it is not that the flag is moving; it is that your honorable minds are moving."
>
> -- Platform Sutra

An assessment paradigm is a point of view for organizing, synthesizing, and interpreting data. EMAP cannot do everything for everyone, but an assessment paradigm implies that it will do something for someone. A paradigm is a necessary point of departure for the discussion of the more specific goals and objectives. Recognition of a particular viewpoint helps to see how EMAP-Forests relates to other viewpoints and therefore other monitoring efforts; this helps to identify a unique paradigm as a *raison d'etre*. Ecclesiastes' statement that "there is nothing new under the sun" more or less applies to environmental measurements; the uniqueness of assessments may be more a matter of interpreting measurements in unique ways.

The National Research Council Committee on Forestry Research (NRC 1990b) advocated an "environmentalism" paradigm that complements traditional paradigms (e.g., utilization, conservation, and preservation) to guide forestry research into the 1990's. According to the NRC report, the environmental paradigm (Leopold 1949) is a global version of Leopold's classic land ethic which holds that "... a thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community..." Sustainability, maintenance of diversity, and aesthetics are examples of concerns that are valued in the environmental paradigm (NRC 1990b). Humans are viewed as participants in the environment rather than as independent observers, users, preservers, or conservers of the environment.

Adoption of the environmentalism paradigm may not be a "safe" strategy for EMAP-Forests assessments. To put it bluntly, the concepts of environmentalism are imprecise and the scientific merit is challenged. Even though public opinion polls show that environmental values are very important to society, there is neither social nor scientific consensus about what the paradigm means. The danger is that an absence of consensus can lead to dissipation rather than focusing of assessment efforts. On the other hand, embracing a more familiar paradigm (e.g., utilization) may seem easier, but risks being incomplete and redundant.

While Leopold's world-view is often cited by ecological scientists, it is not at all clear how to best use the paradigm. The current situation can be compared to airplane design in the 1920's: any interpretation of the basic idea is all right so long as the thing flies. If evolution of airplane design is an analogy, the most useful and accepted versions of a "scientific" paradigm may eventually emerge. The futurist Alvin Toffler (Prigogine and Stengers 1984) noted that "...science is an open system embedded in society and linked to it by very dense feedback loops...its development is shaped by cultural receptivity to its dominant ideas," and a U.S. Federal Court concluded essentially that "science is what scientists do". These statements suggest that even though environmentalism is scientifically ill-defined at present, it is still a valid world-view within which scientists may practice their professions.

In any science, axioms and rules set the stage for theories and hypotheses, and permit consistency of inferences. The observation that the environmentalism paradigm lacks objectivity is not fatal; no science can claim true objectivity except in the context of the accepted axioms and rules (Penrose 1989). So the real issue is that scientists have not agreed upon the axioms and rules of environmental science. Until consensus is reached, the paradigm will best be used as a general guide to help define environmental values of concern. As a practical matter, the specific questions of monitoring design and data synthesis will require recourse to more familiar sciences.

2.3 FORESTS AS AN EVOLVING PROGRAM WITHIN EMAP

The role of forest monitoring in EMAP is an evolving one. As EMAP-Forests moves toward the multi-agency FHM program, it is vital that the goals and objectives of all participating agencies are considered. Currently, EMAP-Forests and FS personnel are striving to accommodate the objectives of both agencies. This process will continue to be vital as additional federal and state agencies and universities begin to participate in the FHM program.

A major aspect of the EMAP-Forests approach to long-term monitoring is maintaining options. One example is the design strategy that utilizes a uniform grid, allows for unbiased samples, allows enhancement of the grid to meet special sampling needs, and allows post-stratification of data. Another example of maintaining options is the indicator approach (see Section 3). The focus is on a suite of indicators which can be modified over time. There is an emphasis on establishing an effective indicator development process that will allow indicator refinement. This process is built around assessment endpoints, encouraging long-term indicator evolution. Similarly, the EMAP-Forests approach to assessment is an effort toward maintaining options for the future (see Section 7). This approach is designed to allow a range of data assessment possibilities from annual statistical summaries with a rapid turn-around time to more in-depth studies resulting in interpretive reports.

A second major aspect of the EMAP-Forests monitoring approach is the effort to base the multi-agency FHM program on the strengths of each participating agency. For example, both the EPA and the FS bring particular strengths to the FHM program. The EPA has a national focus with emphasis in quality assurance (QA), air and deposition data, climatic programs, and a national pool of scientific expertise. The FS has a regional focus with experience in large field programs, working with state agencies, and a strong background in forest science research.

As the multi-agency FHM program evolves, it will be important to continue to highlight and utilize each agency's areas of expertise.

2.4 FIVE-YEAR STRATEGY

2.4.1 Multi-Agency Cooperation

At present, the FS and the EPA are the major agencies participating in the FHM program. So far, the program has remained in the east. Since there has not been significant western representation at planning meeting and workshops, there may be biases in design, logistics and indicators towards the east. In 1991 an effort has been made to incorporate western representation into FHM. This includes the state FS, and the National Forest System as well as FPM and FIA. Meetings on the concepts of FHM were held in December 1990 and January 1991 for western FHM participants. There is a possibility that the states of California and Colorado will participate in some indicator testing on a small set of plots in 1991. In 1992 California and Colorado will be fully implemented.

As FHM expands to all states, other agencies will be included in FHM. The SCS already is involved with field sampling of soils. Other agency involvement would include the National Park Service, the Bureau of Land Management, and the Fish and Wildlife Service to name a few. These groups will have input into the FHM program through formal processes, as additions to the Advisory Council (Figure 2.7) and interagency agreements and informal processes as peer reviewers and by personal communications. By 1995, when full implementation is anticipated, the agencies that play major roles in the FHM program will be recognized. These agencies will form the nucleus for the development of the program towards the future.

2.4.2 Implementation

The FHM implementation schedule is currently being planned by the FS (see Table 2.2). EMAP-Forests will follow this schedule. However, the FS may not implement the full suite of indicators in a region if some indicators have not had previous use in the region and there is a question of whether or not they will provide comparable results to other regions. EMAP-Forests will provide pilots and demonstrations (see section 3) before full implementation of these indicators and will follow the implementation schedule as depicted in Table 2.2.

Table 2.2. Forest Service-FHM implementation schedule as currently planned and the predicted number of FHM plots

EMAP-F Sample Plots Worksheet

1990		1991		1992		1993	
State	For Area	State	For Area	State	For Area	State	For Area
CT	1,826	CT	1,826	CT	1,826	CT	1,826
ME	17,607	ME	17,607	ME	17,607	ME	17,607
MA	3,225	MA	3,225	MA	3,225	MA	3,225
NH	4,987	NH	4,987	NH	4,987	NH	4,987
RI	405	RI	405	RI	405	RI	405
VT	4,544	VT	4,544	VT	4,544	VT	4,544
Total	32,594	NJ	2,007	NJ	2,007	NJ	2,007
Plots	206	AL	21,725	AL	21,725	AL	21,725
		GA	24,242	GA	24,242	GA	24,242
		DE	390	DE	390	DE	390
		MD	2,703	MD	2,703	MD	2,703
		VA	15,968	VA	15,968	NY	18,506
		Total	99,629	NY	18,506	PA	16,826
		Plots	630	PA	16,826	VA	15,968
				WV	12,127	WV	12,127
				FL	16,549	FL	16,549
				KY	9,888	KY	9,888
				MS	16,990	MS	16,990
				NC	18,953	NC	18,953
				SC	12,257	SC	12,257
				TN	13,309	TN	13,309
				MN	16,709	MN	16,709
				CO	21,486	CO	21,486
				CA	38,947	CA	38,947
				Total	312,176	IL	4,300
				Plots	1,973	IN	4,400
						OH	7,120
						MI	12,919
						WI	15,351
						AR	17,687
						LA	13,883
						IA	1,561
						MO	20,226
						WY	10,028
						OR	21,602
						WA	21,520
						Total	462,773
						Plots	2,925

3 STRATEGY FOR INDICATOR DEVELOPMENT AND IMPLEMENTATION

The EMAP program seeks to: (1) describe current ecosystem status, (2) identify long-term changes in ecosystem status, (3) characterize the components of ecosystem change, and (4) suggest avenues for diagnostic research. To complete these objectives, the program has adopted an indicator-based approach to the assessment of ecosystem condition (Knapp et al. 1990). This approach assumes that: (1) indicators of specific interrelationships between ecosystem functions (e.g., rates of nutrient transfer, capacity for nutrient conservation, level of redundancy of function, etc.) are known, (2) indicators can be related within an assessment framework to specific changes in ecosystem condition (e.g., growth, morbidity, mortality), and (3) indicator measurement at a national survey scale is logistically, economically and technically feasible. When the above criteria for indicators are not met, procedures have been established to evaluate options for the development of new indicators, to assess potential utility of these indicators within the existing assessment framework, and to evaluate the need to develop new or additional assessment frameworks. This section describes the strategy and procedures that EMAP-Forests will use to complete this component of the program.

3.1 DEVELOPING A CONCEPTUAL FRAMEWORK FOR ASSESSMENT

The forest health monitoring (FHM) program will assess the effects of multiple stresses on forest ecosystem condition. Ecosystem processes are linked to spatial and temporal combinations of environmental components (climate, soils, topography, vegetation, trophic structure, etc.). Therefore, the success of an indicator and of the corresponding modeling and assessment program will depend on the development of an appropriate diagnostic framework for identifying major resources of concern, suggesting research priorities, and defining attainable conditions of sustainable ecosystem health. This framework should be developed around a regional concept, recognizing that the nature of problems and solutions vary among definable, ecological regions. The framework should focus on the development and application of a suite of tested indicators and models that accurately predict risk to specific ecosystem subpopulations. It should also provide guidelines for specifying the most reliable models for determining ecosystem risk for various stress-management scenarios.

3.1.1 Scale of Ecosystem Response Characterization

The FHM personnel will develop an assessment framework within which indicators may be used to characterize ecosystem condition and/or be aggregated into some common index of condition (or predictor of impending change). It is necessary to adopt or develop models of forested ecosystem structure and function that embody the most current hypotheses regarding the inter-relationships among ecosystem functional components.

Ecosystem response to stress is a function of the magnitude of perturbation resulting from the stress (acuteness of damage), the area exposed to the stress (extent), and the capability of the ecosystem to eliminate or ameliorate the damage (resiliency). It is therefore impossible to extricate the assessment of an areal response from that of the component ecosystems' responses. It is also impossible to develop an assessment of areal effect without first making assessments of the range of ecosystem responses expected within the predefined area and the proportion of the resource in question for which loss is politically and/or economically acceptable (i.e., relative value judgements).

Careful consideration should be given to the scale at which assessments among indicators are made. Application to a regional estimation of forest condition requires aggregation of fine scale results, usually through some statistical estimation of the regional distribution of the various environmental components employed in the conceptual model's representation of processes. It is not obvious whether or not the statistical aggregation of fine scale process simulations on selected sites will be superior to simple models applied directly at the regional scale. Consequently it is desirable that, if possible:

1. Comparisons are made at the spatial scale at which the models will ultimately be used to estimate forest condition.
2. Differences in input data should be minimized so that differences in output most strongly reflect the effects of model structure.
3. Differences among model predictions due to differences in model structure should be distinguished from differences in calibration data sets, aggregation error, etc.
4. Opportunities for combining the advantages of different modeling approaches should be explored.

Appropriate scales for ecosystem response characterization can be addressed through a set of procedural steps common to regional ecosystem assessments (Figure 3.1). While the objectives of each step are the same for any region or stress, the level of available analytical data will likely vary for both regions and pollutants. Several factors cause this variability: disparate understandings of the key processes in different ecosystems and the state of development of data bases for different regions. Decision criteria relating to the elements inherent in each step, as described below, should be considered.

1. Articulate and prioritize regional issues and stresses and identify indicators of condition. To incorporate consistent decisions into regional analyses, a set of issues, stresses, and assessment criteria must first be defined and prioritized. These define the goals of the data analysis. For example, issues of concern common to loblolly pine forests in the southeastern United States might include compiling information about the potential for long-term production, the spatial and temporal periodicities of insect damage, and/or the most appropriate management strategies for different locales within the region. The types of environmental data that are compiled, analyses and interpretation techniques that are performed, and graphic products that are produced all hinge on these issues. Assessment criteria selection sets limitations on the parameters characterizing ecosystem response, thus defining thresholds of condition. Assessment criteria development requires the selection of "indicators" that are representative of the criteria (see Sections 1.4 and 3.1.4). It may also require the development of information about the state of the ecosystem in the absence of anthropogenic stresses to bound expectations of attainable ecosystem quality (Section 3.1.4.4).

2. Data compilation. Available environmental data that appear to cause or reflect the issues of concern should be collected. For a study of the effects of ozone on loblolly pine forests, for example, this might include compiling information about air mass movement and stagnation, monthly weather patterns and insolation, prevailing wind directions and speed, landforms

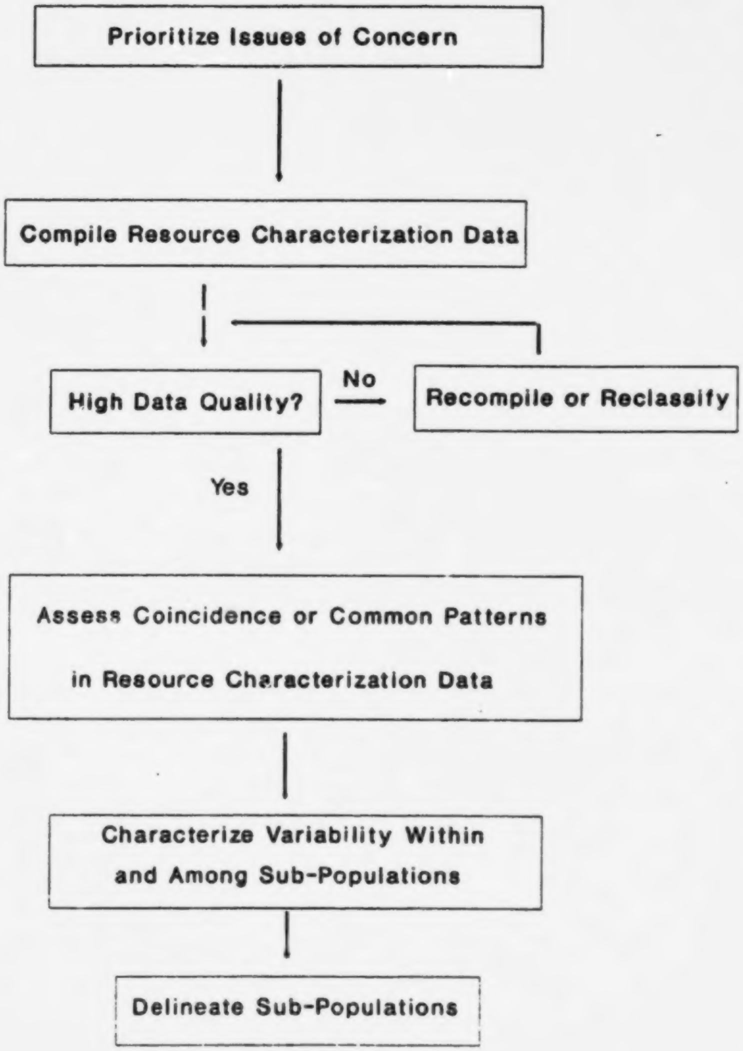

Prioritize Issues of Concern
Compile Resource Characterization Data
High Data Quality?
No
Recompile or Reclassify
Yes
Assess Coincidence or Common Patterns in Resource Characterization Data
Characterize Variability Within and Among Sub-Populations
Delineate Sub-Populations

Figure 3.1. Regional assessment.

(elevation, slope, and aspect), soils (type, moisture holding capacity, and nutrient availability), distribution and background data on loblolly pine forests (management practices and tree growth), and sources of atmospheric pollution (volatile organic compounds and nitrous oxides). Digital and non-digital maps, points, and tabular data can also be included.

3. Data quality assessment. A percentage of each point or tabular data set should be examined for concurrence between sample site locations and descriptions, for the number and types of methods from which the data are derived, and for assurance that data values are scientifically plausible. Maps should be examined for documentation or indication of the resolution and reliability of the data used to generate the maps.
4. Synthesis of new data layers. Data sets can be reclassified or combined to generate new data sets. Numeric data can be sorted into classes to detect spatial geographic patterns in the data that might relate to other environmental characteristics. Several data sets can be combined to create classes that represent composite characteristics.
5. Regionalization. Regionalization (or delineation of response sub-populations) is important because stress exposure can only be altered on a regional, as opposed to an individual ecosystem scale. It is also important because significant sub-populational responses (e.g., high elevation spruce fir) are more likely to be detectable in shorter time frames than are those of the greater population.
6. Resource characterization. In addition to mapping or calculating the extent of the response sub-populations, it is important to document the range in conditions within sub-population types and, if possible, any trends of change.
7. Stressor characterization. Characterization of exposure to stresses at multiple scales (temporal and spatial) is important for correlation and pattern analysis based on historical and current ecosystem status, model calibration, and estimations of ecosystem condition under alternative exposure scenarios. This information may come from multiple sources such as atmospheric models, site-specific wet and dry deposition measurements, interpolation techniques, or from combinations of these approaches.
8. Selection of model and response characterization. Some models have been used to predict how changes in exposure are reflected in ecosystem status change. Many model types (e.g., statistical or process) may exist to predict response to a particular stress or combination of stresses. Each model type has benefits and disadvantages that limit or favor its use in any particular application. The application of multiple models to any particular issue can provide increased confidence in the predictions if the models are properly validated and if the predictions are convergent. If the predictions are divergent, multiple models can provide a basis for identifying additional research needs.
9. Ecosystem response presentation. An integrated approach to forest condition assessment and the presentation of such information must represent complex, discontinuous, and spatially-distributed factors regulating ecosystem responses to imposed stresses. Maps should be capable of displaying comparisons between ecosystem response and stress load, and of comparing population characteristics within and among regions.

3.1.2 Defining Forest Health

A major use of indicators in EMAP will be to assess condition or health of ecological resources. Rapport (1989) lists three approaches or criteria commonly used to assess ecosystem health: (1) identification of systematic indicators of ecosystem functional and structural integrity; (2) measurement of ecological sustainability or resiliency (i.e., the ability of the system to handle natural or anthropogenic stress loadings; and (3) an absence of detectable symptoms of ecosystem disease or stress. Thus, ecological health is defined as both the occurrence of certain attributes that are deemed to be present in a healthy, sustainable resource, and the absence of conditions that result from known stresses or problems affecting the resource.

For any ecosystem or aggregate of ecosystems, many available options and methodologies describe the "health" or condition of the resource of interest. Section 3.2 presents the generic approach that the EMAP program is proposing for the development of ecosystem condition and response indicators prior to their implementation in the national monitoring program. Discussions focus on the identification of decision criteria rather than the presentation of a suite of indicators of forest condition.

3.1.3 Use of Assessment Endpoints

The FHM reports on the condition of forested ecosystems will be based on indicator(s) response(s). These responses represent the quantifiable changes occurring in some components of the forested ecosystem. The balance of indicator response (net and relative magnitudes of change in positive or negative direction) however, reflect societal values of forested ecosystems. The EMAP-Forests assessment framework recognizes the differing uses to which forests are placed. Societal values can therefore be described as fitting into one of three broad categories:

- Ecological Integrity - The concept of ecological integrity recognizes the importance of maintaining ecosystem functional capacity and considers both biological and abiological resources.

- Economic Value - The economic value represents the capacity for the system to generate both direct (e.g., sales) and indirect (e.g., regulation of water availability for agriculture) sources of livelihood.

- Sociologic Value - This value incorporates the intrinsic desires of society to maintain some parts of the world in a "natural state" and includes recreational and aesthetic components.

To provide a structure bridging the gap between societal concepts of value and the measurement of quantifiable components of the ecosystem, a number of assessment endpoints should be identified (see examples in Table 3.1). Using such a structure, it is possible (and likely) that any individual indicator will be interpretable in the context of several societal values. For example, soil chemical analysis data will be used in developing interpretations for the assessment endpoints of soil productivity, soil weathering rate, soil contamination, and nutrient cycling balance.

An example of the relationships in the assessment framework is presented in Figure 3.2. Reading the figure from right-to-left, the societal value serves as the focus through which all assessment endpoints can be interpreted. The assessment endpoints encompass broad categories of ecosystem component characteristics. The aggregation of these characteristics defines the status of the ecosystem. The FHM program will provide information on the condition of the assessment endpoints (i.e., quantifiable characteristics). However, policy offices are responsible for making recommendations that relate to societal values (e.g., whether mitiga-

TABLE 3.1. Examples of relationships between societal values, assessment endpoints, and indicators.

Societal Value	Assessment Endpoint	Indicator
Ecological Integrity		
Abiotic Resource	Soil erodibility	Soil surface recession Gully formation/density Stream sediment load
	Soil productivity	Chemical analysis Nutrient ratios Available nutrients Microbial biomass
	Soil weathering rate	Textural analysis Caption Exchange Capacity (CEC), Anion Exchange Capacity (AEC) Mineralogy
	Soil contamination	Chemical analysis
	Soil water retention	Moisture percent Tension lysimeters Piezometers Climate history
	Water quantity	Gaging weirs
	Water quality	Water chemistry (in cooperation with MAP-Aquatics) Stream physical structure (related to habitat quality)
	Air quality	Air chemistry Visibility Particulate scavenging rate
Biotic Resource	Biodiversity	Floral & faunal species Landscape distribution Habitat quality/contiguity Populational mixing

(continued)

TABLE 3.1. (continued)

Societal Value	Assessment Endpoint	Indicator
Biotic Resource (continued)	Nutrient cycling balance	Soil chemistry Foliar chemistry Sec. carbohydrates Index development PAR
	Contaminants	Foliar chemistry Histopathology Fecal analysis
	Quality of animal resource	Genetic diversity (populational mixing) Census taking Food source quality Fecundity
	Quality of vegetative resource	Foliar chemistry Vertical structure Species diversity Regeneration rate Growth rate Net primary productivity Damage surveys Pathological surveys Symbioses (floral & faunal)
	Landscape characterization	Species range Niche exploitation Patch dynamics Regeneration requirements
Economic Value	GNP from forest products	National/state economic reports
	Biomass by FP category	Harvest inventories Mensurational monitoring Harvest category ratings

(continued)

TABLE 3.1. (continued)

Societal Value	Assessment Endpoint	Indicator
Economic Value (continued)	Water export	Gaging weirs Agricultural irrigation rates Municipal water consumption Hydroelectric water flow rates
	Habitat provision	Fish hatchery counts Stream physical structure (related to habitat quality - joint with EMAP-Aquatics)
	Tourism and recreation	National/state economic reports USDI accounting reports
Sociologic Value	Designated use/usability	User fees/counts Animal counts/sex ratios Responses to visitor surveys
	Pristine quality	Landscape characteristics Management history Land use history Acres of wilderness Road density Age of forest (successional history)

tive action should be required). These recommendations will not be contained in FHM reporting. Indicators may be comprised of individual field measurements or aggregations of field measurements; they are the technical base for quantifying the characteristics of the assessment endpoints.

3.1.4 Application of Indicators

Indicators carry no capacity to assign a value judgement. They serve as a "tag", marking a point of condition in time and space which can be applied to multiple perceptions of value. Assessment endpoints depict the distribution of indicators or may be statistical representations of indicator distributions. A specific example of the scheme relating values and indicator measurements by interpretation through assessment endpoints is presented in the bottom half of Figure 3.2. In this case, total soil and foliar carbon and nitrogen are measurements made as part of the soil and foliar chemistry indicators. Measurements of wet and dry nitrogen deposition at off-frame network sites can be modeled to provide estimates of deposition to on-frame sites. The integration of these components provides information regarding the status of nutrient transfers among these pools and thus the net nutrient cycling balance of the soil-biotic matrix. The addition of an available nitrogen

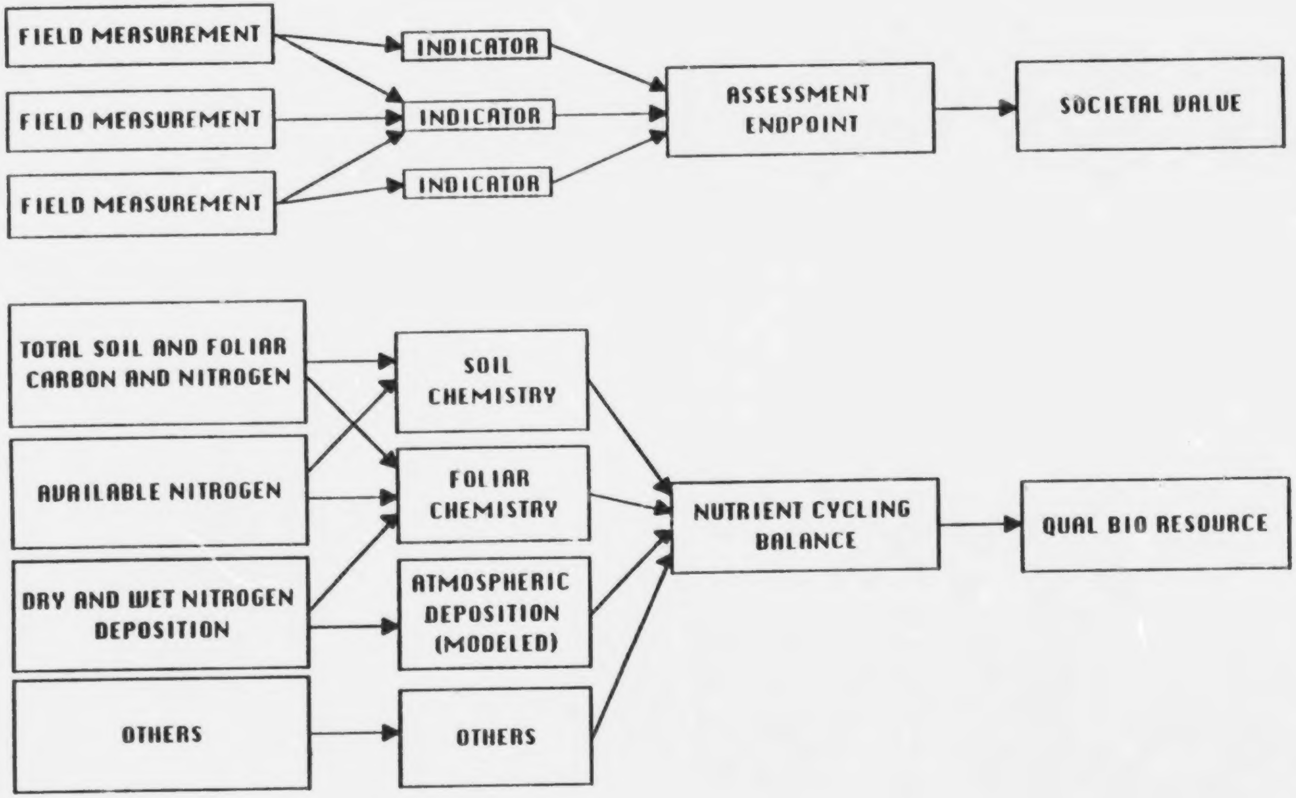

FIELD MEASUREMENT
FIELD MEASUREMENT
FIELD MEASUREMENT
INDICATOR
INDICATOR
INDICATOR
ASSESSMENT ENDPOINT
SOCIETAL VALUE
TOTAL SOIL AND FOLIAR CARBON AND NITROGEN
AVAILABLE NITROGEN
DRY AND WET NITROGEN DEPOSITION
OTHERS
SOIL CHEMISTRY
FOLIAR CHEMISTRY
ATMOSPHERIC DEPOSITION (MODELED)
OTHERS
NUTRIENT CYCLING BALANCE
QUAL BIO RESOURCE

Figure 3.2 Forest health monitoring (FHM) assessment framework.

measurement offers the opportunity to aggregate these data into an index of potential capacity for soil productivity. This index may provide the capacity for estimating optimal balances of these two nutrients in differing forested ecosystems or regions. The distribution of the nutrient cycling balances attained by differing sub-populations within a region could then be used to provide a quantifiable assessment of regional system resiliency (i.e., bounding levels describing the known experience and condition). A shift of the indicator outside this known distribution may signal the onset of system dysfunction. For a more detailed discussion of integration and assessment, see Section 7.

3.1.4.1 Indicator Selection Criteria

Knapp et al. (1990) identified a number of criteria for indicator selection. Table 3.2 is copied from their document. This section describes the criteria that must be applied to the selection of indicators. Existing constraints in meeting these criteria would lead to the selection of indicators on an interim basis while additional information is collected that would enable the use of a more desirable set of indicators.

- Societal Value - Changes in indicator status should result in a willingness to manage stress sources. Though policy-makers can be advised of the significance of an array of technically relevant indicators, the willingness of society to accept regulation on the basis of indicator changes must also be considered. The values that society places on forested ecosystems can be aggregated into three categories: ecological integrity, economic value, and sociological value. These three categories drive the EMAP-Forests monitoring program. All indicators selected for implementation must be interpretable in an assessment context (see Sections 3.1.3 and 7 for further discussion) that has a direct relationship to these values.

- Ecological Integrity - The ecological integrity of a forested ecosystem is a function of the quality of and interactions between its component parts (i.e., abiotic and biotic elements). There is a growing awareness that the "health and quality" of the human condition is inextricably linked to the "health" of the ecosystems people inhabit and the use to which ecosystems are placed (e.g., waste disposal). Humankind is learning that the term "ecosystem" is a function of multiple scales. For example, the source of atmospherically deposited stresses to a watershed may be thousands of square kilometers, the affected vegetation in the watershed may occur in only a few square kilometers, and the area affected by the watershed's export (larger streams and groundwater) may again be thousands of square kilometers in area (see Section 3.2.3 for a discussion of reporting strategy incorporating broad spatial resources).

- Economic Value - The economic value of forested ecosystems lies in marketing vast quantities of forest products each year, management of forests for tourism (e.g., national park system and private souvenir vending), and many other services that are currently treated as external to the goals of forest management *per se*.

- Sociological Value - The sociological (or aesthetic) value placed on an ecosystem is an intangible quality stemming from a sense of personal value found in nature.

- Conceptual Model Output - Because the FHM assessments of forest condition will be made using conceptual models as hypotheses of forest structure, function, and response, indicators included in the

Table 3.2. Indicator selection criteria.

	Critical Criteria
Regionally Responsive	Must reflect changes in ecological condition, pollutant exposure, or habitat condition, and respond to stressors across most pertinent habitats within a regional resource class.
Unambiguously Interpretable	Must be related unambiguously to an assessment endpoint or relevant exposure or habitat variable that forms part of the ecological resource group's overall conceptual model of ecological structure and function.
Simple Quantification	Can be quantified by synoptic monitoring or by cost-effective automated monitoring[1].
Index Period Stability	Exhibits low measurement error and stability (low temporal variation) during an index period.
High Signal-to Noise Ratio	Must have sufficiently high signal strength (when compared to natural annual or seasonal variation) to allow detection of ecologically significant changes within a reasonable time frame.
Environmental Impact	Sampling must produce minimal environmental impact.
	Desirable Criteria
Sampling Unit Stable	Measurements of an indicator taken at a sampling unit (site) should be stable over the course of the index period (to conduct associations).
Available Method	Should have a generally accepted, standardized measurement method that can be applied on a regional scale.
Historical Record	Has an historical data base or a historical data base can be generated from accessible data sources.
Retrospective	Can be related to past conditions by way of retrospective analyses.
Anticipatory	Provides an early warning of widespread changes in ecological condition or processes.
Cost Effective	Has low incremental cost relative to its information.
New Information	Provides new information; does not merely duplicate data already collected by cooperating agencies.

[1] Most important in selecting core indicators (phase 5).

monitoring plan must be specifically included (or amenable to inclusion) in conceptual models of forest condition and response. See Section 3.1 for a more complete discussion of the FHM strategy for conceptual framework development.

- Specificity and Sensitivity - Indicators adopted by the program must be sensitive to changes in stress exposure and/or reflective of the long-term changes in forest structure. They must be operationally definable in terms of some measurement or combination of measurements. See, for example, the discussions of the soil productivity and foliar nutrients indices in Section 3.1.4.3.

- Application - In addition to the selection of an indicator, its form of expression must also be considered. For example, an indicator such as available N may be expressed in the following ways: (1) as the percentage of samples which fall below or exceed some threshold value; (2) in terms of changes in the median value; or (3) in terms of the percentage of map units that contain ecosystems below some threshold value. The choice of an indicator and reporting format reflects the desire of decision makers as well as the ecological relevance of the information and the structure of available data bases.

3.1.4.2 Indicator Categories (from Knapp et al. 1990)

A key element of the EMAP approach is the linkage of indicators to assessment endpoints. Potential indicators are identified using conceptual models of ecosystems, followed by systematic evaluation and testing to ensure their linkages to the assessment endpoints and their applicability within EMAP. The models used may be based either on current understanding of the effects of stresses on ecosystems, or on the structural, functional and recuperative features of "healthy" ecosystems. Important information about assessment endpoints falls into one of the following categories: condition of the ecosystem, exposure of the endpoint to potential stressors, or availability of conditions necessary to support the desired state of the endpoint. To provide appropriate linkage between assessment endpoints and indicators, indicator development in EMAP will produce indicators that fall into one of four categories (Hunsaker and Carpenter 1990):

1) Response indicators represent characteristics of the environment measured to provide evidence of the biological condition of a resource at the organism, population, community, or ecosystem levels of organization.
2) Exposure indicators provide evidence of the occurrence or magnitude of contact of an ecological resource with a physical, chemical, or biological stress.
3) Habitat indicators are physical, chemical, or biological attributes measured to characterize conditions necessary to support an organism, population, community, or ecosystem (e.g., availability of snags, substrate of stream bottom, vegetation type, extent and spatial pattern).
4) Stress indicators are natural processes, environmental hazards, or management actions that effect changes in exposure and habitat (e.g., climate fluctuations, pollutant releases, species introductions). Information on stresses will often be measured and monitored by non-EMAP programs.

3.1.4.3 Indices as Aggregate Indicators

One of the objectives of FHM will be the development of "Indices of Integrity" for forest ecosystem populations and/or subpopulations. Although these indices will not be used as the summary reporting and assessment framework, they will provide additional information in the development of interpretive reports (see Section 11) when used as independent indicators of status and change. Such indices are developed by assigning weights (or importance values) to individual variables representing (or integrating) key functionalities of the ecosystem. The weighing of any specific variable (e.g., foliar C/N ratio) can vary regionally or even by species, depending on the "encountered range" of that variable in the baseline population (see Section 3.1.4.4). This approach has been developed for fish communities (e.g., Karr 1981; Karr et al. 1986), has been applied in regional frameworks (Miller et al. 1988), and has been used in the development of rapid bioassessment protocols for streams and rivers (Plafkin et al. 1989). Figure 3.3 illustrates a generic example of how an integrity index might be used in an assessment endpoint context. The choice of an index score that is representative of the subpopulation (placement of vertical dashed line) is likely to be regionally specific and can be addressed in a "technical context" by comparison to the baseline condition. It can also be addressed in the FHM interpretive summaries. However, the "allowable" magnitude of curve shift in a "sub-nominal direction" (i.e., proportion of the regional population that society is content to let become "less healthy") is a policy issue and is not within the purview of the FHM interpretive assessments.

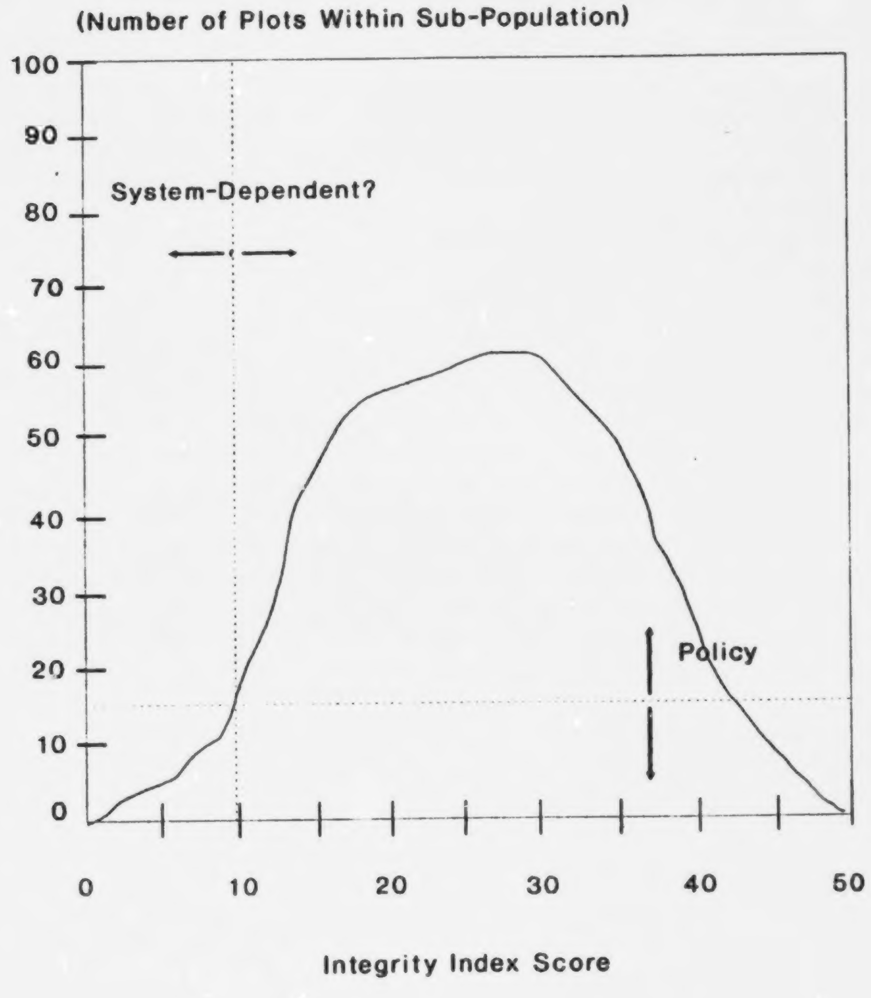


Figure 3.3. Application of integrity index.

Peer workshops conducted during 1989 recommended the likely near-term success in developing soil productivity and foliar nutrients indices. Pilot field activities were conducted during the summer of 1990, and data analyses are examining the feasibility and logistical issues surrounding these indices. Development of the soil productivity index has advanced the most for several reasons. There is a large volume of information available from the agricultural and soil science research arenas and from the Direct/Delayed Response Program (Church et al. 1989). Discussion of the developmental status of each index follows.

Soil Productivity Index

Many researchers have written qualitative or quantitative descriptions of the relationship between vegetative growth and soil or foliar chemistry. An overview of soil rating systems in the United States is presented in an excellent review by Huddleston (1984). Though much of the productivity rating research has been done in an agricultural setting, the concept has also been applied to erosion studies (Bruce et al. 1988), and its application to forestry and forest soils is generating even greater interest.

Possible soil measurements include economically and logistically feasible parameters that are important to determine and monitor soil productivity. Physical parameters such as drainage class and physiographic position have been used repeatedly in growth response studies. Many of these same parameters are being measured as part of the FHM soil monitoring activities.

Though considerable research has been devoted to the identification of soil processes that are important in forest vegetative response, the necessary parameters have not been linked together in a summary index or model that is suitable for application on regional or national monitoring scales. An intermediate evaluation technique known as "collapsed classification" (Miah et al. in preparation) is being developed, however, and may serve as a precursor to eventual summary indices. Based on a factorial design utilizing confounded blocks (Cochran and Cox 1957), this intermediate framework enables data users to evaluate status and trends through a multivariate partitioning technique that aggregates different parameter ranges of concentration into appropriate response groups. It is believed that key soil productivity variables identified in the intermediate framework could eventually be combined into an index or subindex that identifies, on a regional basis, the effects of degradation of soil quality on vegetative response and other general indicators of forest condition (Ott 1978).

Significant advances have been made in the development of indexing systems. To develop indices of forest condition, EMAP-Forests personnel are attempting to acquire data from forest resource scientists. Recent research suggests that the Diagnosis and Recommendation Integrated System (DRIS) indexing system (Beaufils 1973) and Timmer ratios might establish associations among various soil and foliar measurements and forest mensuration data. Both techniques utilize various configurations of parameter ratios that attempt to identify optimal ranges of concentration for specific responses such as vegetative growth. These approaches will be evaluated for applicability within the FHM assessment framework.

Parameters that are expected to serve as inputs to soil indices are being tested. The parameters are configured into "parameter groups" that are defined by similar or associated types of variables (e.g., macronutrients). Data for individual parameters will be weighted according to the relative importance (e.g., macro- versus micronutrient, root toxic, etc.) for forest response of each parameter within a parameter group. Each parameter group will be subjected to a subsequent weighing function (that may vary across regions or forest cover types) as part of the calculation of an index for a given aggregation. An investigation into this facet of indicator development has been initiated.

From a sampling design standpoint, an index should be constructed to represent the actual status of forest condition with respect to the endogenous plot composition. An index should allow trend assessment for a given plot or region over a given time period. For a specific index such as soil productivity, the component parameters of interest should be limited to those operative properties that are known to influence productivity (e.g., soil moisture status, clay content, organic carbon content, surface horizon thickness, etc.). It is unlikely that an index could be based strictly on classification by soil genesis or other non-operative taxonomic criteria.

Operative properties should be amenable to aggregation or dispersion to a level that is necessary to define appropriate configurations that can be used to interpret the assessment endpoints of interest. In the application of DRIS, for example, the index initially could be derived by using equations to determine appropriate ranges and confidence intervals for the independent variables of the DRIS norms. Later applications would capture dependent variables from other FHM indicators as they are implemented. Ultimately, the index might be used to express overall relationships with respect to the assessment endpoints or the population characteristics of interest. Because of this, the index must be able to accommodate and account for differences in parameters, methods, and procedures that are used to measure forest status across all regions of the United States.

Foliar Nutrients Index

Foliar nutrients and chemical contaminants have been proposed as 'Exposure-Habitat' indicators in EMAP-Forests (Hunsaker and Carpenter 1990). Nutrient deficiencies often affect growth or produce characteristic visual symptoms that are indicators of disruption of normal physiological function. The diagnosis of foliar nutritional status may allow for the description of deficiencies or excesses in one or more elements, where significant external evidence of foliage/tree disturbance is present. Quantitative measurements of foliar nutrients may correlate with visual symptoms that are due to gaseous air pollutants such as the ozone-induced reductions in N, P, K, Ca, and Mg (Allen, personal communication), or the deposition of foliar toxins. In the absence of visible symptoms of disturbance, nutrient deficiencies/imbalances of potential toxins, may serve to explain past and future growth reductions. The goal of this indicator is to describe the relative nutrient balance of trees as opposed to quantifying individual concentrations of a few 'important' nutritive elements. The development of a basic understanding of how nutrient stress and contaminants limit forest stand productivity is an essential first step if FHM is to detect changes in growth and/or to predict whether or not they will occur due to changes in climate, atmospheric pollutants, carbon dioxide, or silvicultural practices.

The proposed variables for analysis include elements considered to be essential to plant growth and several potential contaminants. This indicator and the associated variables are consistent with other international forest monitoring programs such as Canada's Acid Rain National Early Warning System (ARNEWS), the United Nation's International Co-operative Programme on

Assessment and Monitoring of Air Pollution Effects on Forests, and the Nordic Council of Minister's Integrated Monitoring in the Nordic Countries.

Foliar nutrient concentrations are known to vary in response to a number of biological, structural, and environmental factors. These factors need to be accounted for to reduce excessive variability. Temporal variation of nutrient concentrations in plant tissue exists from year to year, within year, and within season. Minimizing or accounting for the potentially high between-year variation is of paramount importance to successful trend assessment. Temperature and precipitation patterns have been associated with annual alterations in foliar nutrient concentrations (Leaf et al. 1970). Thus, techniques for quantifying the influence of weather patterns on foliar elemental concentrations (Bickelhaupt et al. 1979) will be evaluated in future assessment activities.

Stability of elemental concentrations throughout the sampling period is necessary to ensure interpretability of samples that are collected during the ten-week field season. Nitrogen, P, and K concentrations in deciduous foliage generally increase early in the growing season and decrease during or after periods of rapid leaf growth. Seasonal changes in other nutrients vary by species and soil (Alban 1985; Woodwell 1974). Since foliar collections will be confined to one site visit during the ten-week field season, the sampling procedures have been designed to limit nutrient variability resulting from sampling of tissue.

Variation between trees within plot may be due to such factors as age of tree, crown class, and soil characteristics. Sampling of the previous year's coniferous foliage will control much of the expected between-tree variation. In stands of relatively low site index, the between-tree variation in nitrogen concentrations was lower in one-year-old needles as opposed to current year growth.

Element concentrations are also known to vary within a tree, by position in the crown, and age of foliage. Several different patterns in foliar nutrient distribution within tree crowns have been reported for various species. Sampling will be restricted to full sun foliage in the upper third of the crown to eliminate this component of variability during sampling. Concentration with site index and soil nutrient concentrations are both important to the proposed use of foliar nutrients/contaminants as exposure/habitat indicators.

3.1.4.4 Establishing Baseline Condition

Inherent in the application of the FHM assessment framework is the realization that the central issue in today's assessments of environmental health is not: "How do we return ecosystems to the undamaged state?" Given that ecosystems are continually changing and that humans will never be removed as a major impact upon the environment, attention must instead focus on determining what remediation level can realistically be attained for a given locale versus the societal concept of desired condition with respect to designated area use. Due to the differences in ecosystem inter-relative functions and human use levels, this question will be answered differently at different points on the globe.

The assessment of ecosystem response to environmental change requires that baseline conditions be determined which incorporate historic variation in ecosystem status. The baseline approach estimates the state of the ecosystems in the absence of anthropogenic disturbances. Future ecosystem status would then be compared to the baseline state. The baseline approach addresses natural variability in the attainability of ecosystem condition and recognizes that a proportion of the ecosystems within a given region may never achieve a predefined level of "health". Techniques useful in this inference include dendrochronology, historical record examination, pedogenic examinations, and isotopic ratio characterizations. This information in and of itself does not define the reference condition, but describes regional population distributions in a less anthropogenically-impacted state. Both the inherent variability of ecosystem response (spatial and temporal) and the variability in ecosystem characteristics (e.g., internal acidity sources) can be identified by this approach.

As a hypothetical example of how baseline sub-regional/sub-population information might be used in an ecosystem characterization framework, consider the policy-assessment question: "What is the distribution of regions where a specific forest species can be expected to grow well?" The specific questions that a regional demonstration may answer are:

- What is the range of a particular species where it is the dominant species and is vigorous?
- What is the range of the species where it is dominant but not vigorous?
- What is the range where the species is vigorous but is not dominant?
- What is the range where the species is present but neither dominant nor vigorous?
- What is the range where the species is not and cannot be located?

This information provides a data overlay that can be used to seek parameters within each of these ranges which covaries with the species range (e.g., available soil nutrients, moisture, temperature, elevation, etc.). After these parameters are identified, the groupings of co-occurrences can be mapped, thus delineating an empirical model of expected ranges. Given this model, it will be possible to evaluate actual monitoring data in the context of scenario projections as to how the species range will shift in response to changes in stress(es) distribution (e.g., global climate change, human population shifts, or atmospheric pollution). Such estimates can then be included in interpretive reports evaluating discrepancies in rates of change between environmental parameters and ecosystem components.

3.2 INDICATOR DEVELOPMENT PROCESS

The proposed approach is designed to provide information about ecosystem condition that is relatively free of interpretation bias. This will provide user flexibility which is vital to the differing needs and priorities of the large client base served by EMAP. The framework is designed in the form of a progressive flow diagram with specific decision criteria driving progression from one level to the next (Figure 3.4). The framework guides indicator development through an assessment process that considers needs and objectives, acceptable data uncertainty, appropriateness of available analytical procedures, data management procedures, statistical procedures, and the need for integrative assessment among multiple indicators. Thus, assumptions inherent at each phase of indicator development are formally considered and presented for peer review. Forcing formal consideration of assumptions is perceived as essential to the uniform development of indicators suitable for a national monitoring program because program design and selection of measurement criteria are often based on the "cumulative learning" and/or opinions of the participating personnel. Specific phases of the development process are discussed in more detail in sections 3.2.1 - 3.2.5.

The strategy for implementing the indicator development process is presented in

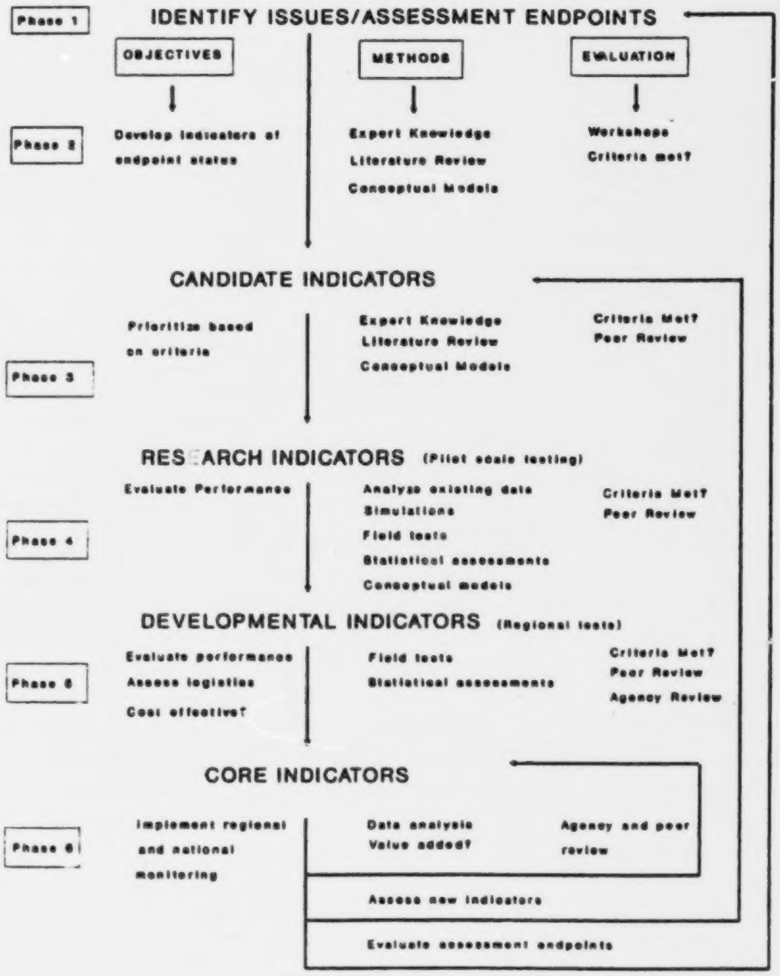

Phase 1
IDENTIFY ISSUES/ASSESSMENT ENDPOINTS
OBJECTIVES
METHODS
EVALUATION
Phase 2
Develop indicators of endpoint status
Expert Knowledge
Literature Review
Conceptual Models
Workshops
Criteria met?
CANDIDATE INDICATORS
Prioritize based on criteria
Expert Knowledge
Literature Review
Conceptual Models
Criteria Met?
Peer Review
Phase 3
RESEARCH INDICATORS (Pilot scale testing)
Evaluate Performance
Analyze existing data
Simulations
Field tests
Statistical assessments
Conceptual models
Criteria Met?
Peer Review
Phase 4
DEVELOPMENTAL INDICATORS (Regional tests)
Evaluate performance
Assess logistics
Cost effective?
Field tests
Statistical assessments
Criteria Met?
Peer Review
Agency Review
Phase 5
CORE INDICATORS
Phase 6
Implement regional and national monitoring
Data analysis
Value added?
Agency and peer review
Assess new indicators
Evaluate assessment endpoints

Figure 3.4. Flow diagram representing the indicator development process.

Figure 3.5. Briefly, the strategy recognizes that:

1. Indicators must be developed and used within a unifying framework that represents the best current understandings of integrated forested ecosystem process and functionality (i.e., conceptual and/or dynamic process models).
2. "Health" is a relative term which can best be described by the range of conditions distributed throughout a population.
3. Though individual measurements of state variables are expected to serve well as indicators of forest ecosystem condition, all individual components of the system exist in an interdependent balance. Thus, the development of indices that aggregate

→ DEVELOP MULTIPLE CONCEPTUAL FRAMEWORKS (MODELS)

STAND DYNAMICS
PROCESS-ORIENTED

→ CHARACTERIZE FOREST POPULATION DISTRIBUTIONS

BASELINE STATUS AND EXTENT
REFERENCE CONDITION

→ DEVELOP AGGREGATED INDICES OF INDICATOR EVALUATION

SOIL PRODUCTIVITY INDEX
FOLIAR NUTRIENT INDEX

→ PHASED IMPLEMENTATION OF THE DEVELOPMENT PROCESS

SPATIAL
TEMPORAL

→ INDICATOR DEVELOPMENT PILOTS THROUGH IAG AND CO-OPS

NEW INDICATORS AND/OR INDICES
MODIFICATION OF METHODOLOGIES
ENHANCEMENT OF ASSESSMENT FRAMEWORK
REGIONAL IMPLEMENTATION VIA FS IMPLEMENTATION PRIORITIES

Figure 3.5. Indicator development and implementation strategies.

multiple components' responses (e.g., the balance of nutrient flows between plants and soils may reflect differences in state capacity and actual state) are expected to provide an "early warning" of the onset of system dysfunction prior to the appearance of symptomology.

4. The FHM program will not be capable of implementing a completely integrated program immediately. For example, some indicators are better suited for immediate implementation due to historical research and development (e.g., examination of crown condition), and some may be better suited to implementation in specific regions of the country (e.g., longer-lived trees provide longer history for dendrochrono-logical reconstructions of disturbance). Therefore, indicator development and testing will be early priorities of the program, and implementation of full-scale monitoring will proceed only after successful testing (criteria and procedures described more fully in sections 3.1.4.1 - 3.1.4.3).

5. The technical research community has the expertise to develop and test indicators. The primary means of infusing new indicators into the monitoring process will be through cooperative and interagency agreements with universities, research institutes, national laboratories, and other federal agencies.

3.2.1 Identification and Evaluation of Candidate Indicators

The purpose of the identification and evaluation step is to propose indicators best suited for characterization and monitoring purposes. Indicators reflect the nature and application of assessment endpoints, must characterize the forest resource, and are the primary means of reporting ecosystem status. For any ecosystem, a number of candidate indicators exist that could be selected. Because there are a variety of levels at which assessments may be conducted, the EMAP indicator development framework is designed to foster comparability among disparate assessment approaches by distilling the process to a common set of steps. Selection of candidate indicators for research and developmental testing will be a function of several interacting factors:

1. Whether or not a linkage can be made with the assessment endpoints (Table 3.1). Inclusion for development in the monitoring program will be tied specifically to how well the proposed indicator is expected to feed into and enhance the assessment framework (Section 3.1.3).
2. The availability of data. Are data available which were collected in a manner appropriate for application in a national or regional context (i.e., represented in models, representative of regional resource distribution, indicative of ecosystem change, etc.)? Large quantities of data are already in existence that can be analyzed to characterize ecosystem condition and to develop response models. In cooperation with the FS-FHM, FIA, and Forest Pest Management (FPM) programs and through the multi-agency information management agreements that will be developed (see Section 10), FHM will gain substantial capacity for adding and/or improving indicators for the monitoring program. The level of available analytical data will probably vary for both regions and stressors because of disparate perceptions of the key operational processes at differing ecosystem scales and varying degrees of data base development for different regions.
3. The consequences of uncertainty. There is always a component of uncertainty associated with an environmental assessment. Because the FHM approach will require the linkage of multiple components in the stress-ecosystem relationship (estimation of stress exposure, assumption of processes mitigating or exacerbating ecosystem response, and variation in genetic response capabilities of receptor organisms), additive increases in the uncertainty accompanying the representation of system response will result.
4. The characteristics of the ecosystems under consideration. This includes the response characteristics of ecosystems and their spatial distribution. For example, differences in characteristics such as soil depth, physical structure, chemistry, topography, and hydrology may require the use of different stand biomass algorithms to describe the same species. Within any region, these parameters may vary substantially. Hypothetically, this would create a range of response potentials and diverse baseline conditions within the same region.
5. The spatial extent, magnitude, and temporal domains over which stress exposure occurs. Exposure to a stress

may only be detrimental to forest condition during certain times of the year, and thresholds of critical exposures may differ both spatially and temporally. Estimation of ecosystem condition requires an understanding of how an ecosystem will respond over time to differing stresses and stress loads. This estimation must be based on an understanding of the physical, chemical, and biological processes involved in response and will be further complicated by synergistic effects between stresses (e.g., acidification effects of nitrogen and sulfur). In addition, special attention must be given to the spatial scale of analysis and to the spatial representation of data because the geographic distribution of forest cover types and responses, stressor deposition estimation, and potential for stress abatement may differ.

3.2.2 Research Indicator Phase (Pilot Testing)

Following identification of candidate indicators that are believed to offer a high likelihood of utility in a monitoring venue, research pilot tests will be conducted to evaluate the suitability of the indicator for regional field trials. Pilot tests will enable analysts to determine whether the indicator will continue to be used in the program, be dropped from consideration, or be "shelved" until new technology makes use more feasible. Figure 3.6 presents a flow diagram that outlines the specific issues that must be addressed within indicator evaluation field pilots.

Pilot studies may be conducted at multiple scales, but the following questions are central to the success of any pilot. "What is the specific objective of the pilot?" "By what pre-determined criteria does FHM evaluate the success or failure of the indicator(s) being tested?" Research must be designed appropriately to answer a specific set of questions with quantifiable certainty. Examples of acceptable objectives for pilot tests include:

- Measurement method modification for regional suitability.
- Hypothesis testing as to whether or not the indicator is related to system condition.
- Determination of the logistical requirements necessary for implementation.
- Comparison of multiple methods to conduct the same measurement.
- Estimation of components of spatial or temporal variability in indicator measurements.

Examples of minimal acceptance criteria warranting advancement to a regional demonstration include:

- Spatial variability less than n standard deviations.
- A specified level of regional covariance with another indicator.
- Measurement error less than n percent.
- Cost effectiveness.
- Field crews must be able to complete sampling in one field day.

The appropriate plot sampling design must be developed after the objectives and acceptance criteria have been established. Insights into this phase should be forthcoming from the candidate indicator selection phase. An objective of a pilot test might also be to select the plot sampling design most appropriate to an indicator. The execution of the pilot study will provide the first-level evaluation point. It will answer questions regarding appropriate field crew make-up, other logistical constraints and needs for implementation, and whether or not the indicator can be implemented in a cost-effective manner.

These questions lead to an analysis of the data collected and its quality. If the data

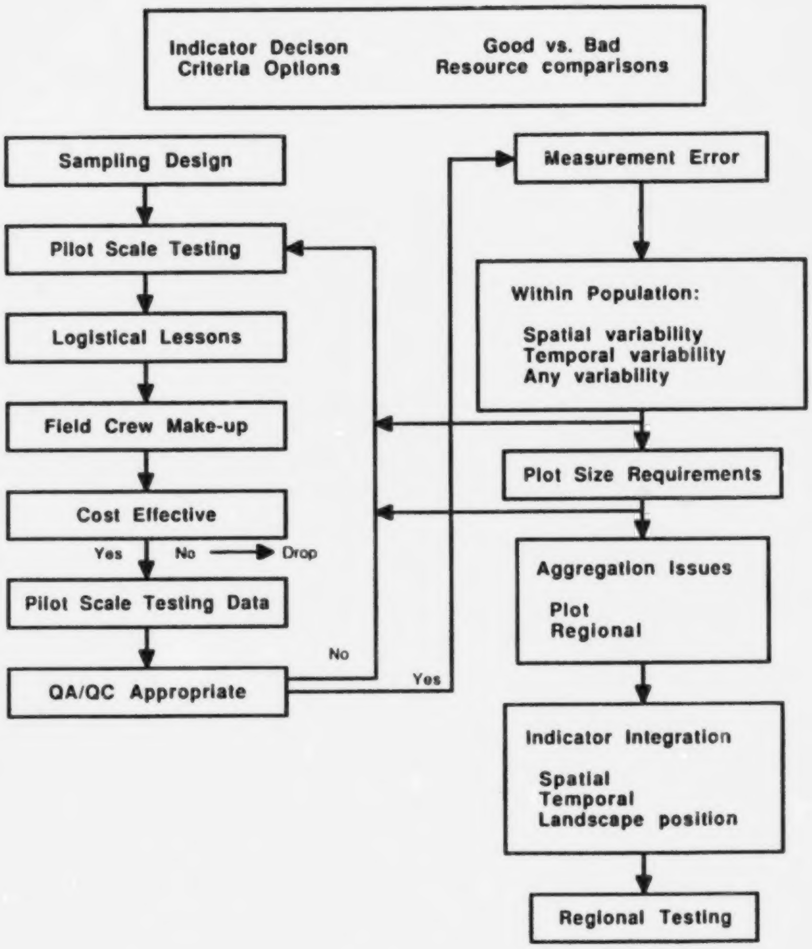

Indicator Decison Criteria Options
Good vs. Bad Resource comparisons
Sampling Design
Pilot Scale Testing
Logistical Lessons
Field Crew Make-up
Cost Effective
Yes
No
Drop
Pilot Scale Testing Data
QA/QC Appropriate
No
Yes
Measurement Error
Within Population:
Spatial variability
Temporal variability
Any variability
Plot Size Requirements
Aggregation Issues
Plot
Regional
Indicator Integration
Spatial
Temporal
Landscape position
Regional Testing

Figure 3.6. Indicator development issues.

meet the required quality criteria, analyses can be completed to determine the utility of the indicator. It is necessary to maintain the program flexibility and delay the progress of indicator implementation to assure the quality, utility (i.e., interpretability within the context of assessment endpoints), and effectiveness of the indicators in the national monitoring program. One aspect of this can be accomplished through modeling evaluations in hypothetical environments. For example, given measured spatial and temporal variances, a mathematical evaluation of the regional sampling intensity needed to obtain reasonable results can be estimated. Such information can be used to provide criteria limits within which an indicator must perform. If the criteria are not met, specific indicators may be dropped from consideration or retested in another pilot study after modification of the measurement procedure and/or plot sampling design. If the criteria are met, an indicator is ready for advancement to the developmental testing phase (regional test). Discussions regarding the status of indicators measured in the 1990 Pilot can be found in Section 3.3.

3.2.3 Developmental Indicator Phase (Regional Testing)

After the successful research pilot testing phase, an indicator is advanced to a regional performance evaluation. In the developmental phase, the indicator will be tested by using the sampling frame, methods, and data analyses intended for the EMAP network. The specific objective here is to identify a subset of indicators that are suitable for full-scale program implementation. These issues will be tested further by using the EMAP sampling and data analysis protocols at regional scales. Regional demonstrations will be used to test whether or not data collected for these indicators are regionally interpretable and to confirm the results of site-specific pilot studies on regional scales. Data from regional demonstration projects will be assessed through peer, agency, and public review of the raw data, regional statistical summaries, and associated interpretive reports. The primary product of this phase is a set of core indicators for implementation in routine EMAP monitoring efforts. As with the research pilot tests, the developmental tests will be focused to achieve specific sub-objectives (Figure 3.7).

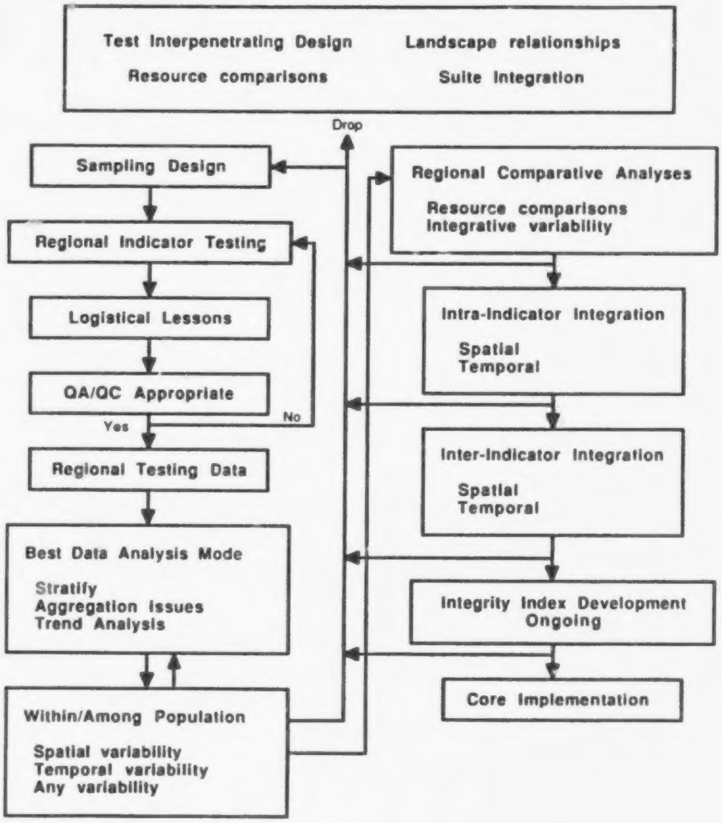

Test Interpenetrating Design
Landscape relationships
Resource comparisons
Suite Integration
Drop
Sampling Design
Regional Indicator Testing
Logistical Lessons
QA/QC Appropriate
No
Yes
Regional Testing Data
Best Data Analysis Mode
Stratify
Aggregation Issues
Trend Analysis
Within/Among Population
Spatial variability
Temporal variability
Any variability
Regional Comparative Analyses
Resource comparisons
Integrative variability
Intra-Indicator Integration
Spatial
Temporal
Inter-Indicator Integration
Spatial
Temporal
Integrity Index Development
Ongoing
Core Implementation

Figure 3.7. Developmental indicator assessment objectives.

Regional demonstration tests provide information such as the most appropriate reporting framework for the indicator and the similarities and differences of temporal and spatial scales of the process and evaluation scheme. Figure 3.8 illustrates one option for developing a reporting framework. The issues of concern are embodied in the assessment endpoint definitions (sections 1.4 and 3.1.3). The regional demonstration provides the resource characterization data necessary to proceed with framework development. Subpopulations can then be delineated representing spatial aggregates of response characteristics (i.e., indicator response or status is more similar within a sub-population than between sub-populations). Information can then be aggregated for analysis and reporting according to these response-similar sub-populations. Such analyses may also focus indicator developmental efforts by providing information about expected spatial variability and hence improving the capacity for development of the most appropriate sampling designs.

3.2.4 Core Indicator Phase (Implementation)

The indicator in question may now be categorized as "core" and is ready for full-scale implementation after all criteria of the developmental phase are met. This phase (re-

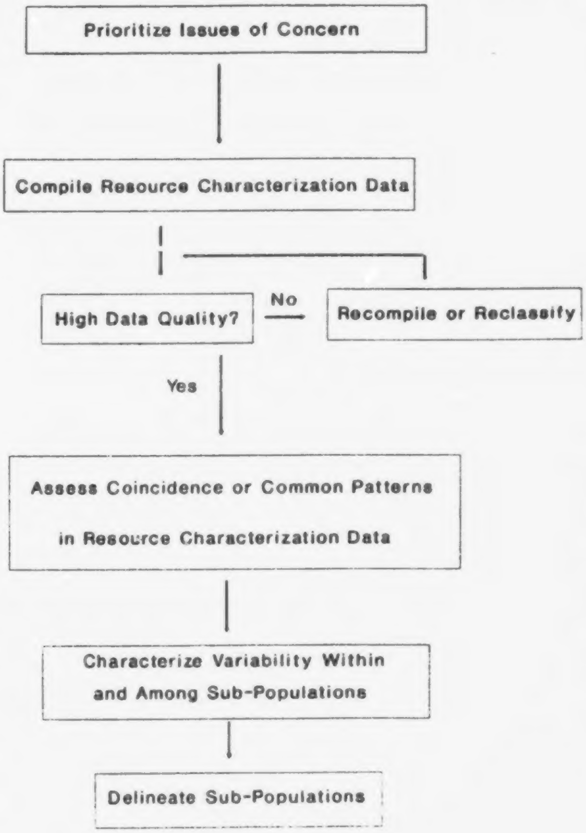

Prioritize Issues of Concern
Compile Resource Characterization Data
High Data Quality?
No
Recompile or Reclassify
Yes
Assess Coincidence or Common Patterns in Resource Characterization Data
Characterize Variability Within and Among Sub-Populations
Delineate Sub-Populations

Figure 3.8. Indicator reporting framework.

evaluating and modifying the suite of core indicators) is an ongoing process that begins upon initial implementation of core indicator monitoring at regional and national spatial scales. This continual process of reinspecting the indicator suite ensures complete indicator coverage of important environmental values, assessment endpoints, and stresses, incorporation of appropriate advances in technology and information, and adequate capability to detect changes and identify trends in the status of ecological resources. In this phase, it is important that EMAP balance continuity of methods (to maximize trend detection capability) with procedures to refine or replace indicators that fail to perform satisfactorily. This phase is implemented through procedures that are designed to critically review the performance of core indicators through a time-series of regional frequency distributions, to evaluate alternative indicators to address emerging issues and inadequate core indicator performance, to add new indicators as deemed desirable, and to substitute superior indicators for inadequate core indicators.

The EMAP monitoring program will document the co-occurrence of stressors and affected populations or sub-populations. Such information is not adequate for the assignment of cause-effect relationships which is not an objective of EMAP. Nevertheless, full-scale implementation of the core indicator suite will provide a mechanism through which other research programs can be focused to fully develop this relationship (Figure 3.9).

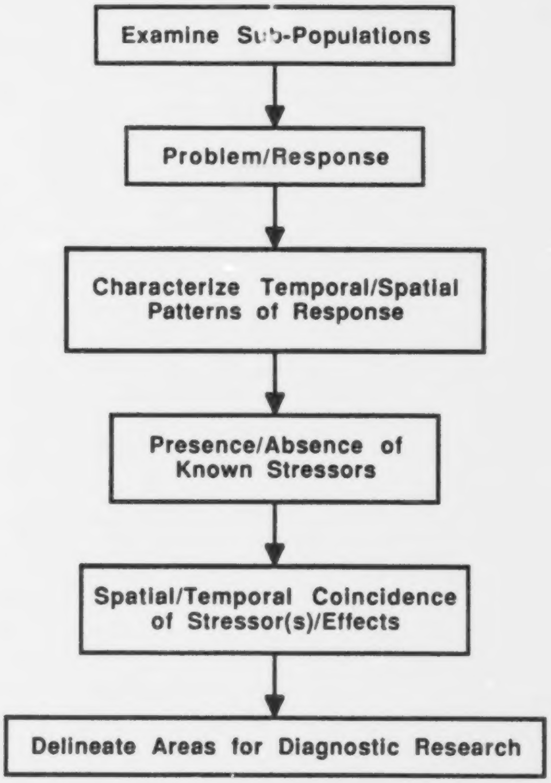

Examine Sub-Populations
Problem/Response
Characterize Temporal/Spatial Patterns of Response
Presence/Absence of Known Stressors
Spatial/Temporal Coincidence of Stressor(s)/Effects
Delineate Areas for Diagnostic Research

Figure 3.9. Pointing toward causality.

3.2.5 Indicator Addition and Replacement

Although reference to indicator acceptance and failure has been made in each indicator section, it is important to point out that the program will not continually add new indicators to the field program. As a national monitoring program, EMAP will add and/or delete indicators depending upon their capacity to provide necessary information to interpretation and assessment. However, the number of indicators to be measured will be strictly limited and prioritized according to the value added in characterizing ecosystem status and trends in condition. Redundancy among indicators providing the same information will be perpetuated only as long as it takes to evaluate their relative value.

3.3 IMPLEMENTATION PLAN FOR FY91

3.3.1 Lessons From FY90 Activities

Figure 3.10 summarizes the status of indicator development within EMAP-Forests. A peer workshop was conducted in the spring of 1989 to identify a number of candidate indicators expected to have a high potential for interpretability and applicability with respect to forest condition. To date, EMAP-Forests has tested six of these in pilot studies. These indicators are percent ad-

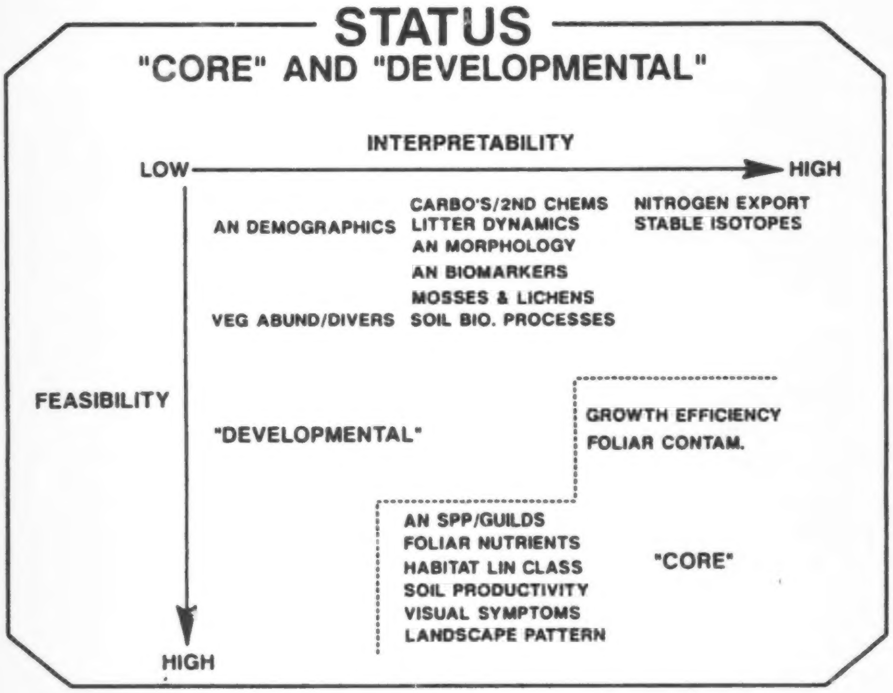

STATUS
"CORE" AND "DEVELOPMENTAL"
INTERPRETABILITY
LOW
HIGH
CARBO'S/2ND CHEMS
NITROGEN EXPORT
AN DEMOGRAPHICS
LITTER DYNAMICS
STABLE ISOTOPES
AN MORPHOLOGY
AN BIOMARKERS
MOSSES & LICHENS
VEG ABUND/DIVERS
SOIL BIO. PROCESSES
FEASIBILITY
"DEVELOPMENTAL"
GROWTH EFFICIENCY
FOLIAR CONTAM.
AN SPP/GUILDS
FOLIAR NUTRIENTS
HABITAT LIN CLASS
"CORE"
SOIL PRODUCTIVITY
VISUAL SYMPTOMS
LANDSCAPE PATTERN
HIGH

Figure 3.10. Status of EMAP-Forests indicator development.

sorbed photosynthetically-active radiation (PAR), vertical vegetation abundance and structure, foliar chemistry, soil characterization and chemistry (see Section 3.1.4.3 for more on foliar and soil indices), growth (mensurational measurements), and visual symptoms. Palmer et al. (1990) provides a complete description of indicator sampling methodologies and design. Samples collected during the summer of 1990 are being analyzed, and statistical summaries are being prepared. Much logistical information was gained including the sampling and data handling and storage and transfer procedures required for these indicators (see Sections 9 and 10). Preliminary examination suggests that the methodologies for all indicators except PAR appear to be satisfactory for movement to the developmental phase. The PAR indicator experienced a problem related to weather conditions and measurement variability; resolutions are being designed. However, final status decisions will not be made until data analyses are completed.

3.3.1.1 Vertical Structure of Forests

The overall objective of 1990 summer activities was to test the utility of forest vertical vegetation structure as an indicator of ecological condition and environmental and anthropogenic stress. Some of the main reasons that vertical structure of forests is proposed as an ecological indicator include:

1) Vertical structure or forest profile has biological relevance as an element of the diversity of plant communities.
2) Animal and plant species richness and diversity is positively correlated with the degree of forest stratification (e.g., MacArthur and MacArthur 1961; Willson 1974; Harper 1977; Dueser and Shugart 1978; August 1983).
3) Conservation and maintenance of animal and plant species diversity has been identified as an important public value.
4) Forest vertical structure is susceptible to anthropogenic stress. For example, forest profile is routinely manipulated by forestry practices such as logging, plantation establishment, and thinning. In some situations forest profile may be greatly simplified (e.g., when mixed-species forests are cleared and replaced by pine plantations) and the associated animal and plant life impoverished (Atkeson and Johnson 1979; Repenning and Labisky 1985; Childers et al. 1986; Felix et al. 1986). Furthermore, structurally simple forests are less tolerant of biotic stresses such as disease and insect attacks (Schmidt 1978; Knight and Heikkenen 1980).
5) Measurement of forest vertical structure is more applicable to detection monitoring than direct measurement of bird, mammal, or insect populations. Measurement of vertical structure is a component of habitat quality. Changes in habitat quality due to forestry or urbanization indicate changes in the quality and quantity of animals (Figure 3.11). Measurement of vertical structure is relatively easy (i.e., sessile organisms) and inexpensive (i.e., one visit by a one- or two-person crew is probably sufficient).

Past and Ongoing Work

While there is sufficient reason for considering vertical structure as an ecological indicator, additional questions need to be answered to justify monitoring forest profile to characterize forest condition and to detect environmental and anthropogenic stress. These questions include:

1) How responsive is forest profile to more subtle forms of disturbance such as thinning or to environmental gradients of moisture and nutrient availability?
2) How well can the effects of anthropogenic stress and stress due to natural factors be separated?

Metric	Measurement Endpoints/Response Indicators	Assessment Endpoint	Societal Value
Number and area, fragmentation, and connectivity of landscape units	Landscape-level habitat condition of forests	Changes in Habitat Quantity and Quality of Forests	Conservation and maintenance of plant and animal abundance and diversity
Species Composition, vertical structure, and patchiness of forest stands	Stand-level habitat condition		

Figure 3.11. Relationships of measurements, indicators, and assessment endpoints for maintenance of plant and animal diversity.

3) Does forest profile differ by forest type?
4) Does vegetation profile change predictably as forests age?
5) What is the spatial variation in forest profile within a region?

Some of these questions have been or are being addressed through two pilot projects: 1) the 1990 20/20 Study and 2) an exploratory analysis of an existing geo-referenced data base of more than 3100 forest inventory plots on the Georgia Piedmont. This analysis is designed to test hypotheses regarding relationships of forest profile with tree species composition, environment, and disturbance. Preliminary analyses of the 20/20 study can be summarized as follows:

1) The ocular method is 2 to 3 times faster (ca. 25 min) than the point method as implemented in the pilot study.
2) The ocular method provides estimates of foliage occupancy that are 2 to 3 times higher (ca. 45%) than the point method.
3) The ocular method gives a less specific profile that has only two dimensions, as compared to the point method.
4) The ocular method and the point method estimate the same number of broad species classes.

3.3.1.2 Soils (1990 20/20 Study)

The overall optimization goal of soil sampling in the 1990 20/20 study was to construct a design that would reduce within-plot spatial heterogeneity within some bounds that would be acceptable to the data users. The two primary objectives of soil sampling in the study were to (1) estimate within-plot and within-subplot spatial variability in soil characteristics, and (2) test the feasibility and logistics involved in implementing soil productivity monitoring on a nationwide scale. The resulting data are expected to be used to optimize the soil sampling design in the 1991 field season and beyond.

The issue of temporal heterogeneity in soil chemistry was less critical to the optimization effort because it is envisioned that the logistics staff will design a plot sampling sequence for each region that will enable each designated plot to be resampled at about the same interval of the index period over the course of the project.

Specifically, the soils staff of the 20/20 Study is investigating:

- Uncertainty stemming from single-hole sampling as opposed to multiple-hole sampling at each plot.
- The utility of compositing master horizon samples while in the field versus compositing the data from replicate master horizon samples.
- Whether the provision of destructive-sampling zones between the fixed-radius subplots will allow collection of soil data that are representative with respect to the forest vegetative data.
- The number of soil holes within a plot that must be sampled.
- Required sampling depths and the types of horizons that should be sampled.
- A determination of whether samples will be composited and at what stage.
- Logistical considerations relating to the resources required to characterize a plot and collect the necessary samples.
- The utility of laboratory analytical methods that were selected.
- Reporting units for the many different soil parameters.
- Identification of any ancillary data that may be needed to link the component variables of the soil productivity indicator.

Logistics information related to the seventh bullet above has already been evaluated. Upon completion of the soil analysis activities in April 1991, relevant questions related to the other nine specific objectives can be answered.

3.3.1.3 Foliar Nutrients (1990 20/20 Study)

The primary objective of this study was to determine the within-tree, within-plot, and between-plot variance components for foliar nutrient and chemical contaminants for the tested sampling design. A secondary objective was to determine the analysis effects of compositing samples within trees. If a primary contributor to the total within-plot variability can be determined, then plot sampling can be designed to reduce the overall variability. Similarly, the study of composition effects is needed to determine where compositing is most effective in terms of cost and variance reduction.

In the Southeast and Northeast, 10 plots were selected for each region from the 40 plots selected for the overall study plan. At each plot, two branches were sampled from each of six dominant/co-dominant trees of the selected species. The visual damage indicator was implemented concurrently on the same trees. The same plots were also selected by the soil nutrient/contaminants indicator for intensified soil characterization.

Foliar samples have been dried, ground, weighted, and placed in storage. Chemical analysis will commence in January, 1991 and data analysis is expected to be completed by April, 1991.

3.3.2 FY91 Pilot Field Objectives

Figure 3.12 summarizes the outcomes of a joint planning meeting between the EMAP-Forests and the FS-FHM planning groups. Briefly, the FS plans to conduct full-scale implementation of the visual symptoms and growth/mensurational measurements within all hexagons in six New England states, Georgia, and Alabama. Additionally, the FHM program will collect soil characterization data at 1/4 of the hexagons in these states (EMAP interpenetrating sampling design).

The EMAP-Forests program will implement a regional pilot study in which it will add soil and foliar chemical analyses and measurement of the vertical vegetation structure and distribution to the FS's list at 1/4 of the hexagons. The objectives of this pilot study are twofold: (1) to characterize the spatial variability in the individual indicators within and among populations in these states (regions), and (2) to test the hypothesis that

OUTCOMES OF JOINT PLANNING MEETING WITH FOREST SERVICE
DEC. 3-6; DENVER, CO

O FS WILL IMPLEMENT IN NORTHEAST, GA, AL, MI:

ALL HEXES
VISUAL SYMPTOMS
GROWTH/MENSURATIONAL MEASUREMENTS

1/4 OF HEXES — SOIL DESCRIPTIVE CHARACTERIZATIONS

O EPA/EMAP-FORESTS WILL CONDUCT REGIONAL PILOT IN NORTHEAST, GA, AL, MI

1/4 OF HEXES
SOIL CHEMISTRY
FOLIAR NUTRIENTS
VERTICAL VEGETATION STRUCTURE/COMPOSITION

< 20 HEXES — % ADSORBED PHOTOSYNTHETICALLY ACTIVE RADIATION

O EPA/EMAP-FORESTS WILL PROVIDE PDR'S AND PROGRAMMING SUPP'T

Figure 3.12. Outcome of joint planning meeting with the Forest Service.

these indicators will be spatially correlated among themselves and with the visual symptoms and growth/mensurational indicators. The purpose in testing this hypothesis is in developing an "early-warning" indicator of change in ecosystem function and integrity. It is hypothesized that the relationship between these individual indicators will change prior to the onset of system dysfunction. The PAR indicator, will also be further piloted at a subset of the same sites to work through the methodological problems associated with varying weather patterns.

3.3.2.1 Vertical Structure of Forests

Three complimentary activities that build upon past and ongoing work are proposed for 1991:

1) Defining the specific objectives for measuring vertical structure in a detection monitoring program.
2) Conducting regional pilots in the Northeast and Southeast specifically aimed at refining the current sampling and measurement procedures for vertical

structure to meet the objectives developed in activity 1 (including defining strata, estimating patchiness, varying number and area of sample units for species counts) and improving real-time remeasurements.

3) Continuing with the analyses of existing data with the objective of conducting "monitoring on paper" for detection and assessment of status and trends.

3.3.2.2 Soils

The primary objectives of soil sampling in the 1991 field season are to:

- Demonstrate that the soil productivity indicator, optimized for available funding and personnel, can be successfully implemented in two large sub-regional forested areas of the eastern United States utilizing a cooperative effort among multiple agencies.
- Continue to develop key components of the soil productivity indicator and evaluate its utility in synthesis and integration with other ecological indicators.
- Begin to construct regional estimates of the concentration ranges for critical soil parameters used in the interpretation of soil condition with respect to the overall assessment endpoints.
- Develop draft data quality objectives for the various levels of soil data collection identified in Section 8 of this document.

3.3.2.3 Foliar Nutrients

The primary objective for 1991 will be a literature review of foliar nutrients/ contaminants. Research will be directed toward the development and refinement of techniques to diagnose nutrient limitation and imbalances in forest stands.

A secondary objective will be to utilize the data from the literature review and the 20/20 Study to perform standard components of variance analysis in the presence of measurement error. System measurement error will be estimated from the 20/20 Study and will be used to begin separating measurement error from variability estimates for within-tree, between-tree, within-plot, and between-plot. Future analysis will address the use of other indicators (e.g., soil nutrients, foliar area index) as covariates.

A third objective is the acquisition of historic data bases that contain data on foliar nutrients for large numbers of trees over at least a three-year period. Analysis of these data bases will address questions of spatial and temporal variability.

Data from the 1990 field pilot studies is being used to examine particular components of variability in foliar chemistry. Other such components will be examined in future field seasons. Although an important first step, it is not enough to use research information to modify design to reduce specific variability components. We must also quantify all components of variability to determine whether or not we will be able to use the data in the EMAP assessment framework. A fourth objective is the design of a field pilot study for implementation in at least one ecoregion for the 1991 field season. The pilot study would serve as a logistics test of a large scale implementation and it would also provide estimates of spatial variability across an ecoregion for non-plantation plots.

3.3.2.4 Visual Damage Survey (Symptoms)

Visual symptoms refers to a suite of pathological and entomological measurements to assist in the assessment of forest health and status and trends of disease. Disease is defined as any deviation in the normal functioning of a plant caused by some type of persistent agent. In the case of decline diseases, a complex of agents including biotic and abiotic components may lead to the diseased state. Visual symptoms measurements are intended to detect any condition falling outside the generally accepted norm for a species (i.e., the baseline). Specific components included are listed in Table 3.3. The measurements proposed have been used in some form in other research projects and established monitoring programs (Anderson and Belanger 1986; Alexander and Carlson 1989; Magasi 1988; Millers and Lachance 1989; Anonymous 1987).

Various methods of estimating foliage amount have been investigated and used to classify tree condition in monitoring and survey projects. Crown density (Alexander and Carlson 1989; Anderson and Belanger 1986) was developed for southern pines. Crown transparency (Millers and Lachance 1989) was developed for sugar maple *(Acer sacharrum Marsh.)*. The European crown rating method (Alexander and Carlson 1989; Anonymous 1987) was developed for use on both conifer and deciduous trees and has been the method of choice by the United Nations Economic Commission for Europe for the past six years. The performance of these three methods will be compared during the FY91 field season. Additional information will be gathered symptoms indicating air pollution exposure documenting the incidence of plants with symptoms (Anderson et. al. 1989).

TABLE 3.3. Visual Damage Survey Variables.

Plot and Sample Trees	Sample Trees Only
Elevation	Tree height
Slope	Height to live crown
Aspect	Density and diameter
Stand disturbance	Increment cores
Air pollution indicator species	Mainstem injury - Type
Tree species	- Location
DBH	Crown - Needle retention (binoculars)
Crown - Ratio (estimate)	- Dieback
- Class	- Dwarf foliage
- Discoloration	- Epicormic branching
- Defoliation	Branch - Needle retention (observed)
	- Needle length
	- Twig symptoms
	- Leaf Symptoms
	- Damage class
	- Discoloration class
	- Discoloration type
	Root signs and symptons

The objectives of the 1991 field program will be to estimate components of variance in visual symptoms (spatial, among trees within plots, and among plots and sub-plots). Comparisons will be made of different methods of air pollution indicator plants (Alexander and Carlson 1989; Anderson et al. 1989) and crown foliage measurements (Alexander and Carlson 1989; Anderson and Belanger 1986; Millers and Lachance 1989; Anonymous 1987). Results will be used to aid in the development of a standard set of methods for the national monitoring program. The visual damage survey is an uncontrolled field survey. Experimental units include both tenth acre and 10-point plots (w493) and sample trees (w1972).

3.3.2.5 Percent Adsorbed Photosynthetically Active Radiation

The Percent Adsorbed Photosynthetically Active Radiation (PAR) indicator is expected to provide information on the use efficiency of photosynthetically active radiation incident to the forest canopy. As a potential surrogate for the more difficult to measure indicator of leaf area index, PAR is planned for use as an indicator related to net stand production and canopy condition, a marker of canopy closure (thus related to expectations in basal increment area growth), and as a component of ground-truth for remote sensing measurements. EMAP-Forests staff have met with various groups by way of background research into the feasibility, utility, and appropriate plot design for the PAR indicator. It is anticipated that the ultimate design will be determined by March.

The basic objectives currently planned for FY91 activities are:

1. Methods development - test continuous ambient sensors to complement under-canopy measurements (proposed to resolve problems associated with variable cloudiness).
2. Plot design - test larger plot sizes, possibly supplemented by pre-stratification from aerial photos, depending on opportunities, and test various plot protocols to determine structure.
3. Assessment - continue making PAR measurements as part of a suite of measurements, and try to link PAR more closely with measures of habitat and vegetation structure. Attempt linkage with those who have satellite data for the locations.

3.3.2.6 Wildlife Condition, Habitat, and Distribution

The status of wildlife is one component of forest ecology that is of mutual concern to EMAP-Forests and to the U.S. Department of Interior Fish and Wildlife Service (FWS). EMAP-Forests is currently exploring an opportunity to develop an Interagency Agreement to improve EMAP-Forests' monitoring design and assessments as they pertain to wildlife ecology. Specifically, the EMAP-Forests program is seeking to increase efficiency in the specification, development, and testing of indicators of wildlife condition and/or habitat, and to improve analysis and interpretation capabilities regarding the status and trends of wildlife components of forests.

3.3.2.7 Landscape Characterization

Because the FHM program is being designed as a multi-agency cooperative endeavor, it is desirable that the systematic EMAP grid sampling design be linked within some type of framework to existing forest health and management monitoring programs such as the FS FIA and FPM programs. Linkages between these existing sampling frameworks can be facilitated through the application of multi-level landscape characterization monitoring.

The first level of the multi-level sample would be designed to permit stratification on permanent landscape features such as landform and forest/nonforest. Several strata could occur in any one 40 km^2 EMAP hexagon. Landform/forest cover delineations would then be used to select a sample framework for high-resolution, second-level photo-plots. For example, nonforested strata might be sampled at a lower intensity to monitor afforestation, or deal with errors in detecting forest cover on low-resolution aerial images. Habitat, forest type, or other criteria that are expensive to apply to entire hexagons might be used to provide a framework for developing extent estimates from plot-level indicator measurement data.

The second level would be designed for inexpensive remeasurements of a few basic indicators of forest health. For example, tree mortality and defoliation may be measured using high-resolution aerial photography and/or videography. Because high-resolution imagery has a narrow field of view, approximately 1 km^2 (250 acres), high-resolution imagery is impractical for complete coverage of each 40 km^2 primary sampling unit. A second-level sample plot is proposed using 3 to 10 second-level photo-plots in each 40 km^2 first-level sample unit to accurately estimate tree mortality and tree defoliation. These conditions are often rare and not spatially contiguous (although there are many exceptions), and large photo-plots would more efficiently quantify mortality and defoliation than smaller field plots. The least expensive indicator would be the number of dead or defoliated trees per unit area (status and extent). However, to estimate the rate of change in mortality and defoliation extent, the number of trees in each second-level photo-plot might have to be estimated from the high-resolution imagery, perhaps via subsampling the imagery. Rate estimation requires that each individual sample tree must be found on two dates of imagery taken 12 months apart, possibly requiring a reduction in the size of the second-level photo-plots to save interpretation time. Detection error may be significant, especially for large plot sizes, and methods should be adopted to estimate the proportion of dead or defoliated trees that are not detected with interpretation of aerial imagery. It might be desirable to use aerial photography once every 5 to 10 years for estimating forest type, tree heights, tree species, regeneration, fuel loading, habitat type, stocking density, and stand development, and to use aerial videography for the same plots in intermediate years for less expensive measurements of tree mortality and defoliation. An interpenetrating rotation between aerial photography and aerial videography is also possible.

FHM plots would be nested within the framework of the 1 km^2 second-level plots to take advantage of the annual monitoring for tree mortality and defoliation at the second-level, disturbance history for each plot interpreted from remote sensing, the need to quantify the error in detecting tree mortality and defoliation with remote sensing at the second-level, and would permit extrapolation of FHM indicator data (sections 3.3.2.1 - 3.3.2.6) to the more extensive spatial framework. This integration within the extensive framework would also provide a mechanism for comparative evaluation of FIA, FPM, and FHM data.

Concerns

Efficiencies and precision are gained by emphasizing remote sensing, but there is limited infrastructure in place to acquire, coordinate, interpret, and archive this source of data. To assure consistency and quality, the remote-sensing activities would have to be institutionalized. Ideally, there would be a small number (maybe one) of units that have direct responsibility for this function. The unit(s) might be branches of existing units with related missions, such as FIA, FPM, or state forester agencies.

Synergistic benefits

FPM currently produces annual assessment reports for insects and diseases in the west. It might be possible to produce these same reports using annual defoliation estimates from high-resolution aerial photography and less frequent field examinations of FHM plots. FPM might be able to make minor adjustments to its current program to contribute to FHM, while meeting its current objectives in a perhaps more efficient and rigorous manner. Similarly, there are several new monitoring initiatives in the west: detection of possible effects from global climate change, and changes in condition of Wilderness Areas. It might be possible to design one or two compatible sampling frames that more efficiently serve several different sets of objectives.

The use of PROGNOSIS as the baseline for growth and mortality can also be used to validate and improve this model. PROGNOSIS is commonly used by the FS National Forest System (NFS) for their strategic planning (e.g., FORPLAN), and improvement of planning models will directly improve NFS management. As part of forest plan monitoring, assumptions used in the planning process must be verified. Models such as PROGNOSIS are regional in nature, and are collections of numerous assumptions on growth and mortality rates that directly affect the land management planning process. Likewise, the use of fuel loading and forest insect and disease risk models as forest health indicators will lead to improvements in those models, with a potential to improve very expensive management actions for fuels, insects, and diseases.

High-resolution aerial photography could be used to reliably interpret forest type, crown closure, and stand development on a sample of FHM photo-plots. A subsample of FHM plots could be very useful for labeling or training digital classifiers of satellite data (e.g., Landsat), and for quality control in the production of vegetation-cover maps. Another subsample of FHM plots could be used to estimate statistical calibration models that correct for misclassification bias in areal estimates. This would be valuable to National Forests and other agencies for reliable mapping of wildland resources in the west, and unbiased areal estimates used in local land-management strategic planning.

High-resolution aerial photography may be suitable for estimating leaf area index or photosynthetic efficiency, which are measurements related to other potential indicators of forest health. This might be tested in future research studies.

3.3.2.8 Indicator Evaluation Field Study Plan Timeline

EMAP-Forests, in cooperation with the FS-FHM, has an opportunity to conduct field studies this year. Arrangements are being made to provide a soil scientist and a forester or plant taxonomist to collect data on one fourth of the FHM plots in New England, Georgia and Alabama in the sampling frame of the EMAP interpenetrating grid. Another individual will also be available on a subset of plots, probably 20 in each of two FS Regions, for smaller scale studies. These measurements will be made in conjunction with the FS-FHM measurements selected by the FS (visual symptoms, soil type characterizations, and growth/mensuration measurements). EMAP-Forests will coordinate closely with the FS and develop an approved field study plan. The following timeline and information has been distributed to staff authoring sections of the FY91 Field Indicator

Measurement Plan and is proposed to accomplish the study plan requirements.

Feb. 1 Letter requesting Demo Proposals in Annotated Outline form and Commitment to Implementation, Analysis and Reporting.

Feb. 8 Section Annotated Outlines Due to Kucera and Strickland. The annotated outlines should address the following FY91 Indicator Evaluation Field Study Plan

Components:

1. Introduction; should include rationale for inclusion of indicator in EMAP-Forests.

2. Objectives; should include statement of specific objectives and anticipated study outputs.

3. Justification; should include literature and/or data analyses which support decision to conduct field work at proposed level (Demo vs. Pilot) and lend confidence that stated objectives and outputs will be met.

4. Approach; should provide all information necessary to serve as a methods manual for field crews. Components of Approach should include:

   - Sample collection procedures: Specific "cook-book" descriptions of sampling protocols.
   - Logistics: What is the anticipated level of the sampling and analysis effort? What specific personnel, qualifications, training, and debriefing requirements are necessary for field crew staffing? Estimate hours per plot required for measurements. Transportation, equipment and consumable supply procurement, communications, preparatory and analytical laboratory, safety, inventory and storage considerations.
   - Information Management: What are the anticipated sizes of the data files that will be transmitting to the central data management group?
   - Design: What within-plot sampling design will be necessary for adequate sampling coverage?
   - QA/QC protocols from sample collection through sample analysis and data entry.

5. Reporting; should provide a description of the anticipated structure for information reporting. What data analysis procedures are appropriate for your indicator? What reporting format will you use in communicating your results? Suggest deliverables.

6. Timeline; Should provide a timeline for: completion of analytical, QA/QC, and data analysis and for delivery of reports.

Feb. 8 Field Study Section Annotated Outlines sent to Support Leads (Logistics, Information Management, QA, Statistics, and Design, Indicator Development, Integration and Assessment, Reporting) and FS-FHM Program Manager and Regional Implementation and Indicator Leads.

Feb. 12 Conference Call 3:00 - 5:00 p.m. EST. FTS 245-4230. Subject FY91 Field Study. Selection of measurement projects. Coordination of field study.

Feb. 28 First draft of Sections sent to editors.

Mar. 13 Edited draft sent out for internal review.

Mar. 22	Reviewed drafts returned to authors.
Mar. 25-27	Authors workshop; internal review reconciliation and possibly meeting with FS counterparts.
Mar. 28	Editing.
Apr. 4-15	Word processing.
Apr. 19	Send plan out for peer review.
May 3	Receive review comments-copy to editor and author.
May 10	Reconciliation sent to editor from author.
May 10-13	Editing and word processing.
May 14	Document sent to laboratory for approval.
May 31	Laboratory approval.
June 3	Pretraining and training.

4 STRATEGY FOR MONITORING NETWORK DESIGN

4.1 GENERAL STATISTICAL REQUIREMENTS

The design of the Forest Health Monitoring (FHM) program must permit statistical estimates of condition and trends with corresponding precision estimates. To meet these objectives, the statistical design must:

- Provide explicit definitions of the target populations and sampling units.
- Provide an explicit definition of the sampling frame for the selection of sampling units.
- Use probability samples on the sampling frame.
- Permit analyses of a variety of possible subsets of the data.
- Adapt to a variety of questions, some of which cannot be specified in advance.
- Have a structure that permits sampling at coarser or finer levels of resolution, as required.

This section will discuss how the EMAP design (Overton et al. 1990) will be used in the EMAP-Forests program and how the above criteria are being addressed in the EMAP-Forests design strategy. The Forest Service (FS) inventories and monitoring programs have been discussed in Section 1. That discussion serves as introduction for the discussion of the statistical designs of the FIA and their relation to the EMAP-Forests sampling frame in this section.

4.2 DEFINITIONS OF POPULATIONS AND SAMPLING UNITS

4.2.1 Populations

To answer questions about the condition and trend of forest ecosystems, target populations and subpopulations must be defined. The FHM target population is defined as the areal extent of forested ecosystem about which estimates of conditions will be made. Target populations can be defined by a region or an attribute. For example, the population of interest might be the forests of the Northeast as defined by FIA units, only high elevation spruce/fir forests, or all stands of sugar maple in the New England area. At the broadest level, the target population for FHM is all forest ecosystems in the United States.

The development of a sampling frame to address forest condition for all forest areas necessitates an exact definition of a forest ecosystem (Section 1.3). This definition is still not sufficient to distinguish forests from some of the other EMAP ecosystems. As an example, forested wetlands could fall into either forest or wetlands ecosystems. Therefore, a cooperative effort between the EMAP-Forests and EMAP-Wetlands resource groups may provide a better coverage of forested wetlands. Similarly, some people might consider areas of chaparral as forest ecosystems; others might consider them to be arid lands and therefore within the EMAP-Arid Lands Resource Group. In addition, areas such as thick, extensive hedgerows by agricultural lands are not clearly the responsibility of either the EMAP-Forests or the EMAP-Agroecosystems resource groups. These lines of division or cooperation must be drawn before the sampling frame and Tier 2 sampling methods can be fully developed. Resolution of these issues is discussed in Section 1.

4.2.2 Subpopulations

Within EMAP, subpopulations are defined as the classes of resource types about which statements of condition and trend are made. In addition, certain subpopulations will delineate any stratification that an EMAP ecosystem group decides to use. Thus, subpopulations serve two major purposes. They increase the precision of condition and trend estimates by reducing extraneous variation and target specific sets of resources for reporting and assessment.

EMAP-Forests has identified 21 particular forest types that can be delineated regionally. In a given region, only two to seven of these 21 constitute major forest types. Other possible variables by which to classify subpopulations include stand size and class, site index, geographical region or ecoregion, elevation or elevation and forest type in combination, and landscape characteristics. Most of these will be used for reporting or post-stratification.

4.2.3 Sample Units

For purposes of sample selection, the population should be divisible into what may be called sample units. The set of all possible sample units constitutes the population as a whole. Identification of each sample unit is necessary to prevent ambiguities in sample selection. There is ongoing discussion with EMAP-Design on the technical details of sample units in the EMAP-Forests context.

Since forested ecosystems do not have simple boundaries, an EMAP-Forests sample unit is currently defined as a contiguous area of forested ecosystem that meets the FHM definition of forest. The monitoring network design will specify a single element in a sample frame as the sample unit, and this will represent an extent of resource. The actual plot size and geometry for Tier 2 purposes is discussed in Section 5.

4.3 EXISTING FOREST SERVICE INVENTORIES AND MONITORING PROGRAMS

There are a number of extant USDA FS inventories and monitoring programs. A number of these have been reviewed by Hazard and Law (1989). Much of this subsection is taken from that document. In the past twenty years, there has been an increasing need for forest resource inventory data. These data have contributed to assessment and management objectives of various agencies and organizations. Of the 16 USDA survey units (see Section 4.4), seven are FIA units and nine are National Forest System (NFS) units. The NFS regions do not always coincide with FIA regions.

The FIA has seven geographic units responsible for surveys. The FIA inventories provide a comprehensive inventory and analysis of the renewable forest resources for Resource Planning Act (RPA) assessments. They provide information about renewable forest resources which is used by resource managers, including state and regional agencies, industrial firms and associations, colleges and universities, and state legislative and congressional staffs. With certain exceptions, the FIA conducts inventories on federal, state, county, and private timber lands. For example, most do not inventory national forest lands or administratively reserved areas such as national and state parks.

The NFS inventories produce resource information for developing, implementing, and monitoring National Forest Management Plans. They also produce resource information for

RPA assessments and survey reports. Resource inventories which are conducted on each national forest may cover a wide range of resources, including timber, range, soils and geology, plantlife, fish and wildlife, natural water occurrences, and quantitative data on species and community diversity. Most national forests exclude wilderness areas and research natural areas from their timber inventories. The National Forest Management Act of 1976 mandates that managers of federal land monitor the impacts of management activities on all resources. Other national forest sampling efforts include the timber sale cruises, regeneration surveys, and soil condition surveys.

The Forest Pest Management Program (FPM) supplements the tree mortality information gathered during the forest resource inventory surveys done by the FS. Their sampling efforts are directed toward forest insect and disease conditions in the United States.

4.4 OVERVIEW OF THE FOREST SERVICE FIA DESIGNS

The FIA projects (Section 1) have partitioned their respective regions into survey units which are geographical areas inventoried as separate, statistical populations. These units are usually defined by enumerating all counties, states, or geographical regions within a well-defined boundary. Exclusions such as wilderness areas are delineated so that the exact acreage is known for each survey unit prior to sampling. However, field measurements are not taken on most areas of exclusion.

4.4.1 FIA Photo Points

Data collection is usually based on double sampling for stratification. This procedure calls for the interpretation of sample points on aerial photographs as the first sampling phase. The aerial photo points are laid out on a systematic grid over the survey unit. Classification of points on this grid provides estimates of forest area, although these estimates may be augmented by the FIA. Classification of the photo points also provides the stratification information to be used in the second stage of the FIA double sample. Classification for this purpose depends on ownership categories, land-use classes, volume classes, and/or major land classes (forest versus nonforest). Several FIA units only stratify by major land class (i.e., whether or not the photo point is forest land).

Sampling intensities vary among FIA regions and among survey units. The photo points range from one point per 190 acres in the North Central region to 1 point per 1,400 acres in parts of the Pacific Northwest region. The frequencies of ground plots generally occur in proportion to the acres in different strata.

4.4.2 FIA Sampling Methodologies

The selection strategies in the second phase of FIA sampling vary among units. The classification from photointerpretation is used to select a stratified probability sample. The ground sample plots commonly consist of a cluster of points located over a one-to-five acre area, although the ground sample plots in Alaska have covered up to twenty acres.

4.4.3 FIA Measurements

The ground plots are usually permanent, although some FIA units use partial replacement or complete replacement of plots over time. The plots are generally remeasured on a ten-year cycle, except in areas of relatively slow or fast change in volume. For example, in Alaska cycles may extend to twenty years.

Measurements on the ground plots provide estimates of stand and individual tree attributes. The measurements fall into four categories: area data, plot data, tree data, and other vegetation data. Area data include aspects of land use, landscape, stand dynamics, and wildlife habitat values. Plot data include plot age, location and history, site index, and soil taxonomic data. Tree data include species, diameter at breast height (dbh), height, cull, tree quality values, tree history, regeneration, and wildlife values as related to merchantability, species, and size. Other vegetation data cover foliage structure, condition, and regeneration information. Sections 1 and 2 discuss the reasons these programs do not meet the needs of EMAP.

4.5 SAMPLING FRAME

In addition to identifying the population and subpopulations of interest and the sample units, it is necessary to develop a sample frame. The sample frame consists of a representation of sample units comprising the population. One way of constructing a sample frame is a list frame, a list of all possible sample units, such as the one used in the National Lake Survey. Since EMAP-Forests is dealing with areas of forest which do not have simple boundaries, a list frame is not sufficient.

An alternative to a list frame often used in a case like forests is the use of a map as representation of the list frame. As discussed in Section 4.4, this is the approach taken by the various FIA units.

The EMAP sampling design divides the conterminous United States into approximately 12,600 hexagons, each of which has an area of 640 square kilometers. Within these hexagons are smaller hexagons, the 40 km^2 landscape characterization hexagons. The hexagons represent a systematic grid with a random start (i.e. the hexagon centers are randomly located by selecting a single random point in space and moving the entire pattern so that some hexagon center is on that point).

In the following discussion, as well as in Section 5, the current design concept of EMAP-Forests will be discussed, along with methods to evaluate that structure.

4.5.1 Tier 1

For the purposes of EMAP-Forests, the Tier 1 resource is the forest resource within the 40 km^2 landscape characterization hexagon of the overall EMAP program. These hexagons represent a probability sample from the larger hexagons, with a sampling fraction of 1 in 16. In the current EMAP-Forests design concept, the entire forested area of each 40 km^2 hexagon is considered to be the potential Tier 1 resource, although this could be modified as a result of pilot studies. The most efficient landscape scale for EMAP investigation is not known at this time. EMAP-Forests personnel will evaluate whether the scale to be used for EMAP-Forests Tier 1 should be at the scale of the field plot, the scale of the watershed containing the field plot, or the scale of the 40 km^2 hexagon.

The importance of landscape-level and watershed-level processes on local or regional forest condition is not fully understood. Furthermore, the importance may vary by scale and by geographic region or ecoregion. There are concerns about the capability of EMAP Tier 1 plots to measure forest conditions appropriately at the landscape level. At the EMAP Tier 1 level, there is a need for more analysis on the optimal (or even minimally acceptable) plot size, spatial sampling intensity, temporal sampling frequency, detail of the forest cover classification system, and the accuracy of the cover classifications. For EMAP-Forests, the grid density or hexagon size may be insufficient, the temporal variability may force the use of more temporally intensive evaluations, or the classification system may be inadequate. The FS has suggested a pilot study to evaluate most of these concerns.

EMAP-Forests is funding an FS pilot study to investigate these concerns. The scale of the proposed pilot study is limited to areas that can be efficiently imaged with high-resolution aerial photography. This establishes a plot size of approximately four square kilometers. The FS interpreted 1985 imagery for a 1.2 percent sample of the state of North Carolina at this scale. This process used 441 plots, each of which is 4 km^2 in size. North Carolina was originally chosen for this study because it encompasses diverse physiographic regions representative of land cover conditions in the eastern half of the continental United States.

The planned pilot study will acquire 1991 imagery of the same 441 plots. Major forest disturbances will be photointerpreted using replicate images taken six years apart. These disturbances will include forest harvesting, regeneration, and land use changes. The ability to detect other disturbances such as defoliation, fire, and windthrow will be investigated. The association of observed disturbances with landscape structure measurements will then be investigated. To test the current EMAP proposal for Tier 1 work, 1:40,000 scale aerial photography will be used. For comparison, much higher-resolution (1:12,000 scale) aerial photography will be used to evaluate classification error and classification detail of the proposed EMAP photography.

4.5.2 Use of FIA Photo Points

Under the current EMAP-Forests design concept, the most viable sampling frame is the FIA photo point grid (Section 4.4.1). This frame permits linkages with the FIA units. This logistical linkage is crucial to the success of the project and may outweigh all other considerations. This sampling frame also provides an immediate probability sample for selecting Tier 2 sites and allows inclusion probabilities for the probability sample to be determined directly. EMAP-Forests is planning to select one Tier 2 site in each hexagon. The FIA photo point grids are not of consistent density across all regions. This does not create any problems within regions, but it means that inclusion probabilities for Tier 2 sites will be unequal when information from different regions is pooled (see Section 6).

The current Tier 2 site selection method is equivalent to the selection of a single FIA photo point. The FIA photo point grid for a region is overlaid on a landscape characterization hexagon. This gives a direct evaluation of the number of possible photo points that could be selected. If the Tier 2 site is selected at random from the photo points in the hexagon, then the inverse of this number becomes the inclusion probability for the selected Tier 2 site at this sampling level.

4.5.3 Tier 2 Sampling

Tier 2 sampling consists of gathering field measurements for indicators on selected sampling units. Under the current EMAP-Forests design concept, the closest FIA photo point to the center point of the hexagon is selected as the location for further field plot selection. The details of site selection and location based on the choice of FIA photo point are discussed in Section 5.

4.5.3.1 Association Rules

The current EMAP-Forests design requires the selection of one FIA photo point within each hexagon. If stratification methods are found to be appropriate (see Section 4.4.3.2), then the following discussion would be appropriate for each stratum of interest. If multiple photo points are selected in some or all hexagons, with or without stratification, then the following discussion would still apply, subject to some modifications.

Once the FIA photo point grid is laid over a landscape characterization hexagon, there are a fixed number of photo points eligible for selection as Tier 2 sites. These sites could be thought of as a list frame, and association rules would be used to select the Tier 2 site from the frame. One possible association rule is to pick the point nearest the hexagon center. The alternative is to treat the set of eligible photo points as a list frame and use a selection method such as Madow's method (Madow 1949).

Under the current design concept, there is not an appreciable difference between these two strategies. The list frame is equivalent to an equal-area selection method because all photo points within one hexagon have the same probability of selection. All points can be associated with equal areas of coverage because the photo grids do not have significant curvature. Furthermore, in either approach the full set of potential sample points will be available for future modifications of the design. The list approach has the advantage that it conforms to standard sampling techniques and is well studied. However, the closest-neighbor approach has the advantage of data confidentiality. Only the site selected would appear in data bases outside of the FIA units, thus protecting the confidentiality of the other FIA sites. This feature currently makes the nearest-neighbor approach the preferred method.

4.5.3.2 Stratification Options

Under the current design concept, the resource is not pre-stratified. Appropriate stratification methods for the effective evaluation of condition and trends in forests have been discussed, but no clear choice of stratification method has emerged. It may be that stratification by current resources would provide non-optimal sample designs for future study of the dynamic forest resource (i.e., sufficient historical data would be unavailable to perform future stratifications at the different levels).

EMAP-Forests is funding the FS to do a retroactive simulation study to address some of the questions of stratification and sampling intensity. In this study, alternative sampling designs would be appropriately applied to select stratified subsamples of existing FIA plots, simulating the selection of FIA phase 1 photointerpreted plots for EMAP-Forests plots. This study could also simulate the use of only EMAP landscape characterization data for sample frame development, allowing evaluation of alternative sample frame approaches. Though complete results would not be available until early 1993, sufficient work would be done by fall of 1991 for incorporation in the national plan for the FHM program.

There are several approaches to pre-stratification that this study would examine. One approach is the current approach in EMAP-Forests that no pre-stratification of resources will be done, with detailed Tier 2 measurements made only on forested plots. Alternatives include the pre-stratification of the sample to enhance the design efficiency, allowing the possibility for different sample sizes in different strata. Any pre-stratification from EMAP or FIA data would be done using imperfect, remotely-sensed classifications. Another alternative would be pre-stratification by landform, which might be advantageous in the western FIA regions. Landform information could be taken from available topographic maps, but there would be classification error due to the map resolution as well as problems with GIS registration of the map information with the EMAP and FIA grids.

Stratification could be done based on current nonforest/forest status. This is the only stratification currently possible in many regions using FIA Phase 1 photointerpreted plots and may be the only stratification feasible for EMAP landscape characterization. Stratification could be done by current nonforest/forest status and evaluation of hardwood/conifer/mixed forest. This should be feasible if EMAP landscape characterization is done on the Tier 1 resource prior to Tier 2 site selection. Stratification could be done by current nonforest/forest status, along with the current 21 Society of American Foresters (SAF) forest types. An underlying assumption is that EMAP-Landscape Characterization would be able to provide more detailed forest delineations than are typically extractable from high-elevation aerial photography. Stratification could also be done using Omernik's ecoregions (Omernik 1987) or ecoregions specifically developed for forest resources.

Another facet of this study is the potential evaluation of minimum-travel-time designs, in which clusters of Tier 2 plots would be selected within a subsample of Tier 1 hexagons. Different levels of classification accuracy would be evaluated in concert with the various stratification methods. Since this approach would involve major changes in statistical design, significant statistical advantages would have to result for it to be used.

4.5.3.3 Schedule of Sampling

The current design concept for EMAP-Forests is the exclusive use of the interpenetrating design, with a cycle time of four years (see Section 2). The grid would be divided into four, disjoint, systematic samples in which all sites would be completely measured in one field season. At the end of four field seasons, the complete set of plots would have been visited exactly once, with complete data collection at that time.

This approach is being considered for the FS FHM program. In 1990, the New England states began monitoring visual symptoms using the EMAP grid design. However, these states plan on annual revisitation of sites with an altered sampling schedule. Under this plan FIA data would be collected at each site every year, and each year one indicator's measurements would be collected across all sites. Scientific reasons exist for checking the new growth and new foliage every growing season. This has resulted in a different approach to sampling and measurement in EMAP-Forests. There are concerns about the efficiency of this design relative to the EMAP design. It is important that this be evaluated as soon as possible, so that the problems of sampling schedule can be resolved for national implementation.

This annual remeasurement plan has several disadvantages. Since the indicators are collected in different years, it may not be feasible to integrate indicator data due to seasonal variability from climatic and meteorological conditions. Revisiting sites every year increases the anthropogenic damage to the site, increases the likelihood that the confidentiality of the site could be compromised, and may increase the difficulty in getting land owner permission to visit the site. In addition, simulations on artificial data done by EMAP and Oregon State University suggest that it would be less efficient to visit all sites every year than to visit the same number of different sites every year for a cycle of four years, using the interpenetrating design.

The FS retroactive simulation study (see Section 4.5.3.2) will also address this concern. One component of the study will examine various schedules of spatial remeasurement. One option is the annual remeasurement of all plots, with annual rotation of the measurement of some indicators. Another option is the interpenetrating design with cycles of 4, 7, 9, and 12 years. Some indicators may not need to be remeasured every four years due to extremely low temporal variability. A third option to be evaluated is the use of the interpenetrating design with a mixture of time intervals. This option would incorporate several remeasurement schedules, including measuring some plots annually or remeasuring some indicators less frequently. A fourth option suggested for evaluation is the cyclic remeasurement of all plots within contiguous regions at specific time intervals (e.g., every four years).

The question of annual remeasurement on a fraction of the sites needs to be addressed in more detail. Simulations on artificial data done by EMAP and Oregon State University suggest that the inclusion of annual remeasurement sites in the interpenetrating design may improve trend detection during the first one to three cycles, after which the improvement becomes negligible. These simulations suggested that annual remeasurement of approximately ten percent of the plots for the first couple of interpenetrating cycles would be a good choice. This could be achieved by selecting one ninth or one twelfth of the plots for annual remeasurement for the first two or three cycles of the survey. If one twelfth of the sites were remeasured annually, then 31.25 percent of the sites would be measured each year, instead of 25 percent. If it is decided to make these annual remeasurement sites a permanent component of the design, then we may try to develop a procedure for periodic partial replacement of these plots, so that they do not become overly impacted by repeated visits.

In addition, a joint simulation study between EMAP-Forests and the New England Forest Health Monitoring program is being designed to resolve the issue of annual remeasurement of all sites versus the use of the interpenetrating design. If this study is done, it would use the visual symptoms data collected during the 1990 field season in New England. These data would be decomposed into the four systematic grids of the interpenetrating design, and temporal variability and measurement error would be assessed from external data sets. Then simulation studies would be performed to determine the relative efficiency of monitoring only a quarter of the sites each year. Various statistical estimators would be evaluated as part of this study, including the estimators specifically discussed in Section 6. Since a major component of site measurement cost for the FIA units is the cost associated with visiting the site, a reasonable relative efficiency associated with the interpenetrating design might be acceptable. An alternative study proposed by EMAP-Statistics and Design would compare these schedules given equal effort, so that the trade-off between these schedules could be assessed.

4.6 HIGHER GRID DENSITIES

Increasing the grid density is the method that EMAP-Statistics and Design recommends for increasing the sample size for any subpopulation. For specific subpopulations, it appears that grid densities higher than the standard EMAP grid will be needed. For example, high-elevation spruce/fir forest occurs only in specific elevation contours. Based on the standard EMAP grid, it is expected that less than five high-elevation spruce/fir forest sites would be obtained in the Tier 2 sample. Another special case applicable to EMAP-Forests is the special interests of particular states. For the 1990 field season for the FS-FHM program in New England, Rhode Island asked for a more dense grid to be overlaid on their state so that they could obtain a sufficient number of sites for statistical evaluations. The standard Tier 2 sample will not address anything less than a resource class.

In each case, it will be necessary to use an iterative process to select such a sample. The first step will be to determine the desired Tier 2 sample size. It is then straightforward to determine if the standard EMAP grid will produce sufficient sites where the sample size is a monotonic function of indicator variability. If it does not, then the density of the grid can be iteratively increased until the desired sample size is obtained. The EMAP design is flexible enough to meet this need.

5 STRATEGY FOR FIELD SAMPLING DESIGN

5.1 INTRODUCTION

Field sampling refers to the collection of Tier 2 measurements that will be used in the calculation of the indicators (see Section 3). This section discusses the plot design approach used in the 1990 pilot studies and the analyses to be used in assessing that plot design.

5.2 PLOT SELECTION RULES

A crucial step in calculating the indicator information is selecting field plots to ensure that the resulting data represent a probability sample. The Tier 2 site selection process using the current design concept was discussed in Section 4.

5.2.1 Connection with Current FIA Plots

In the current design concept, a field plot is chosen using an association rule to select a Forest Inventory and Assessment (FIA) photo point within the 40 km^2 landscape characterization hexagon. After the photo point is selected, the decision of which field plot to use must be made.

Current FIA plots present one possibility. The FHM plot would be overlaid on the site of the FIA plot. The other alternative is the creation of a completely new FHM plot. In the 1990 New England field season, the field plots were laid on top of existing FIA plots, and these plots were considered by the FIA to no longer be FIA plots. There are advantages and disadvantages to each alternative.

The advantage of using a subset of the FIA plots as the Tier 2 sample is the direct linkage with the FIA ground plot system. One disadvantage, however, is that the density of FIA plots varies greatly by state and region, a problem that could result in a more complicated set of inclusion probabilities for the plots and more complicated analyses of the data (see Section 6). Another drawback of this plan is the potential loss of FIA plots from the FIA sample when those plots are used for FHM sampling. The FIA might not want to include plots that are undergoing any destructive sampling, a factor that could lead to biased estimates of some variables.

FIA plots were used in the Northeast region during the 1990 field season. However, because of the Northeast sampling design, this is the only region that can periodically replace plots. Other FIA projects do not want to use FIA plots for FHM sites.

The advantages of creating completely new FHM plots are twofold. This scenario would simplify analysis by providing an unbiased probability sample with equal inclusion probabilities within each stratum in a region. It would also provide an opportunity to correlate FHM data with other data collected at the same location. One disadvantage would be problems of statistical linkage to the existing FIA plot system, a system that presents an enormous source of potentially useful historical data. This problem could be partially overcome in several ways. The FIA photo points would allow links to FIA areal estimates. It should be possible to use FIA definitions of subpopulations to provide links between the FIA and FHM statistical frameworks. Composite estimators could also be used to combine information from the independent samples statistically. A standard method in forest sampling involves combining the estimators linearly using the inverses of the respective variance estimates as weights (Ray Czaplewski, personal communication).

The current recommendation from the FIA units across the nation is to use the existing FIA grid of photo points (see Section

4.5.2), but not to use the actual FIA plots in the future. One photo point per hexagon would be chosen and if there is already an FIA plot in place, the ground plot would then be offset from the FIA plot by a fixed bearing and distance. The FHM plot could also be located at a random bearing or a random distance from the photo point. However, this would not be necessary to achieve the desired probability sample. Careful protocols are being established to ensure that field crews select sites properly.

In areas where FIA photo point grids do not exist, the FIA has shown a willingness to extend the systematic photo point grids to cover all forested lands. The details of this have not been established (see Section 1).

5.2.2 Plot Selection Protocols

Inevitably, there will be problems with the sampling of plots. Plots may be inaccessible or unsafe to sample, lost, or destroyed. Criteria for plot selection must be designed carefully so that a probability sample is maintained.

Plots that are inaccessible for safety reasons (i.e., excessively steep slopes) could be relegated to a stratum of unsampled sites about which no inferences can be drawn, as currently suggested by the Forest Service (FS). Alternatively, these plots could be treated as missing data in their original stratum and left as missing data permanently. Plots which are inaccessible due to landowner denial of access could remain in the monitoring system and be marked as missing data. Permission to gain access would be sought at each scheduled measurement time. Rather than using this strategy, the Northeast region in the 1990 pilot chose to select alternate plots when denied access by landowners. Such plots must be flagged in the data base and the inclusion probabilities for these plots must be altered.

Lost plots are plots that cannot be relocated from the ground. The FS suggests reestablishment of these plots in their correct locations as determined by photo points. The disadvantage of this procedure is that historical data from that plot might no longer be relevant. The alternative would be to declare that all the data for that plot are missing and try to relocate the plot in the future. This must be decided before a measurement cycle is completed and there is an opportunity to lose an established plot.

Established plots may be destroyed in various ways. They may be clearcut, in which case the FS defines them as non-forested plots within the original forest type. In this case, the plot would remain in the monitoring system and be monitored on the same schedule. Plots that are converted to agricultural land would be flagged in the data base as no longer forested land. These plots would be followed until they return to forested land and are monitored on the previous schedule.

5.2.3 Boundary Case Protocol

Some FIA projects "rotate" points in their field plots. In other words, if the plots straddle two or more distinct forest types, the plot is reconfigured so that the subplots fall into the same forest type as point number 1 of the plot. Point number 1 could be the first sampled point in a 10-point cluster, or it could be the center point of a fixed-area plot. Plots that straddle two or more distinct forest types are a concern to the FIA. It has been argued that when such overlap is permitted, unrealistic forest type combinations that do not actually exist are "created".

Points are rotated to facilitate description and simplify analysis; however, the introduction of bias is a possible result. Some FIA projects have adopted specific rotation techniques; other FIA projects do not rotate points. The FIA recognizes that point rotation may bias volume estimation, but it also recognizes that not rotating points may yield biased estimates of area and volume by forest type. Furthermore, the decision to shift points is made by the field crew; therefore, it remains subjective.

A primary concern of FHM is that the bias introduced into the plot selection procedure will invalidate the monitoring network design. The current consensus is the FHM plots should not be rotated, and methods for sampling multiple strata or forest types within a single plot must be developed. An alternative approach is to use subplot information (with appropriately adjusted inclusion probabilities) in estimation procedures. This would allow the use of non-rotated plots that span different forest types without unduly complicating post-stratification or reporting procedures.

5.3 PLOT DESIGN IN THE 1990 PILOT STUDIES

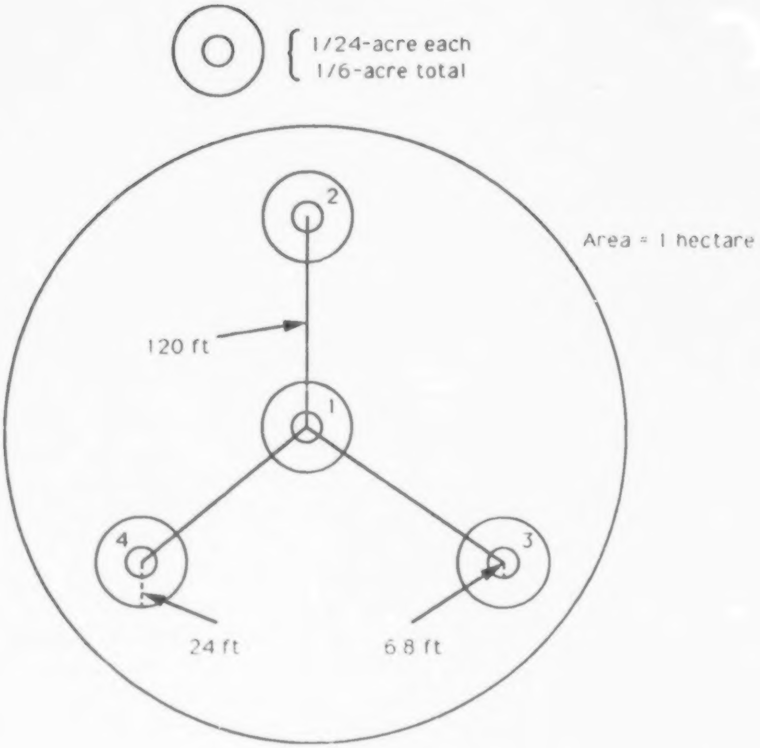
In the 1990 pilot studies in the Northeast and Southeast, the plots, subplots, and measurement locations were configured with specific objectives not necessarily germane to plot design for full implementation of FHM. One objective was assessment of variability components for different indicators. This will not be needed in full implementation. Therefore, the plot design used in the 1990 pilot studies is not necessarily the optimal plot design for future studies.

5.3.1 Plot Geometry

The field plots used in the 1990 pilot studies were fixed-radius plots (i.e. each plot described a circle about the plot center). The FIA projects also have extensive experience with alternative plot designs such as variable -radius plots (i.e., plots in which trees are selected with probabilities proportional to their basal area) and the 10-point cluster (Hazard and Law 1989). Due to the many quantities to be measured, there is ongoing discussion about the plot geometry. As discussed in Section 4, a single, contiguous extent of forest ecosystem was desired as an experimental unit so that a single fixed-radius plot containing a four-point cluster worked well (see Figure 5.1).

Most scientists generally agree that variable-radius plots are more efficient for measuring current status based on tree characteristics such as basal area and volume, but that fixed area plots are easier to use for measuring change over time. Furthermore, variable-radius plots do not have an advantage when assessing current status of indicators not directly related to tree size. For example, the vertical vegetation structure measurement used in the 1990 pilots, although related to forest stand size and density is not more efficient when using variable-radius rather than fixed-radius plots. The use of fixed-radius plots is easily defended on the basis of the variety of measurements to be taken. It is harder to establish fixed-radius plots, but it is claimed that they are easier to remeasure than variable-radius plots. In addition, fixed-radius plots should be easier to use in assessing changes and trends over time because the plot delineations will remain stable.

Thus the fixed-radius plot was selected for the 1990 pilots. Although there are advantages to having a single plot design for the entire FHM program, no plot design can be optimal for all criteria simultaneously. However, at a FS conference on FHM design, it was decided that the current plot design should be used for the national FHM program, with special exceptions only when the design can be shown to be inadequate for particular cases (i.e., sequoia forests).



Distance between points is 120 ft
Azimuth 1-2 = 360
Azimuth 1-3 = 120
Azimuth 1-4 = 240

Figure 5.1. Plot design for the FY90 field season.

5.3.2 Plot Size

The size of the experimental unit in the 1990 pilots was originally defined as one acre. The one acre area was chosen because it has been the traditional size used by the FIA units in the past. An important criterion for the 1990 pilots was a plot protocol with which the field crews would be familiar so that protocol development and training requirements would be minimized.

The FIA defines the minimum area for classification of forest land as one acre (0.40 hectares). Since the pilot project was originally designed for the Northeast FIA unit, the one-acre plot size was considered reasonable. At the time, there was no way of assessing whether one acre was efficient for all indicators. In the actual implementation, the circle covering the subplots extended over approximately 2.5 acres (1 hectare).

5.3.3 Number and Size of Subplots

The design used in the 1990 pilot consisted of four 1/24th-acre circular subplots within the experimental unit - one in the center of the plot and the other three arranged to the north, southwest, and southeast at 120-degree angles from one another (see Figure 5.1). Each subplot had a radius of 24 feet. Nondestructive measurements were to be made on the subplots, and all destructive measurements were to be made off the subplots. This subplot arrangement for the pilot study was acceptable to FHM for assessing plot and subplot variability.

5.3.4 Areas for Destructive Measurements

In the pilot study, destructive measurements on trees were performed in a 12-foot ring around each subplot (see Figure 5.1). It has been suggested that all destructive measurements be done over one crown width from the subplots. This was not done in the 1990 pilot studies. Some FIA units felt that one crown width distance might not be enough to protect the plots from potential confounding effects of increased pest activity associated with destructively sampled trees. Implementation of this rule may necessitate the use of larger plots. Two branches were taken from each sampled tree, and multiple trees were sampled on each subplot. This was done to assess components of variability in foliar nutrients and contaminants rather than as an official method for future foliar sampling.

Destructive soil sampling was done at three points. Each point was midway between the center of the center subplot and the center of one of the other subplots. Since three pits were considered affordable and reasonable based on prior analyses by the soil indicator group, data from the pits were combined to provide data relevant to all the subplot information. In addition to the typical plots, special plots were established with these three pits and nine additional pits that were located in three triangles in the destructive sampling zones of the exterior subplots. This design was selected to provide information on soil spatial variability across a typical field plot. It is not expected that twelve pits on a plot will provide an optimal allocation of resources. Analysis from the pilot data will help determine reasonable choices for the number of samples and the locations of the soil sampling pits.

5.3.5 Linkages Between Indicators

The subplots and destructive sampling zones were laid out so that linkages between indicators might be established. For convenience and investigation of relationships between the measurements, the vertical vegetation structure and photosynthetic active radiation (PAR) measurements were done at the same 16 points on each subplot. The tree samples were taken close to the subplots so that foliar data and destructive visual symptoms data could be related to non-destructive measurements on the subplots. The soil samples were taken to provide plot-level average soil chemistry on typical plots. Special plots provided extra information about soil chemistry within the destructive sampling zones for potential relationships with foliar chemistry.

5.4 PLOT DESIGN DEVELOPMENT

Now that the 1990 field season is complete, it is essential to analyze the data from the pilot studies and evaluate the lessons learned. The primary purposes for the 1990 pilot were logistics studies and assessment of variation components. With cost and time estimates from the pilots, it is feasible to begin assessing optimal ways to sample specific indicators. Many of the samples will not be analyzed by analytical laboratories until March. Thus, information from these data could not be used in this document, but may still be available in time to modify FY91 field activities.

5.4.1 Assessment of Variability Components

For any variable of interest measured on a forest plot, variability in population estimates may arise from a variety of factors. These factors will introduce uncertainty in the estimation of all the population statistics including means, totals, medians, and quantiles. The sources of variability include:

- Real differences in plot-level means across the region.
- Spatial variation between measured values across plots.
- Spatial variation within plots or within subplots.
- Temporal variation between years.
- Temporal variation over the sampling period within the field season.
- System measurement error attributable to the total variation in all the facets of sample extraction, collection, handling, preparation, and analysis.

In the 1990 pilot studies, most indicator variables were sampled so that between-plot variability, between-subplot variability, within subplot variability, and system measurement error could be estimated. Measurement error will be assessed using the quality assurance (QA) remeasurements that were performed as a part of the QA program for the pilots (see Section 8). The other components are determined using analysis of variance techniques.

The standard nested analysis of variance based on plots and subplots within plots will provide three mean squares (Cochran 1977). Let the mean square for plots be s_1^2, the mean square for subplots within plots be s_2^2, and the mean square for observations within subplots be s_3^2. Then one can use the expected mean squares to obtain estimates of the variance components using the method of moments. Furthermore, measurement error can be incorporated and removed from the calculation at the same time.

If n is the number of plots, m is the number of subplots, k is the number of observations within each subplot, f_2 is the sampling fraction for subplots, f_3 is the sampling fraction for observations within each subplot, and s_m^2 is the externally estimated measurement error, then the variance component estimates can be calculated as:

$$S_1^2 = s_1^2 - (1 - f_2)\, s_2^2 / m - (1 - f_3)\, s_3^2 / (km),$$

$$S_2^2 = s_2^2 - (1 - f_3)\, s_3^2 / m, \text{ and}$$

$$S_3^2 = s_3^2 - s_m^2$$

5.4.2 Cost Versus Efficiency

The above variance component estimates can be placed into formulas from Cochran (1977) to yield optimal sampling strategy to balance cost and efficiency. Note that this does not address developing sufficient precision to detect specific trends with stated confidence. This only allows one to assess the optimal arrangement of resources within a plot for a specific cost or a given limit on the size of the variance of the grand mean. The application of Cochran's formulas in the EMAP context requires that inclusion probabilities be approximately equal (see Section 6).

5.4.3 Trend Detection

One of the primary goals of EMAP is to detect trends of ecologically significant size in a specified number of years; therefore, it is important to determine as soon as possible whether or not a specific indicator will be able to meet its data objective. The assessment of this criterion has two requirements. The components of variability must be known well enough to estimate the performance of the indicator in detecting a trend, and the size of the ecologically relevant trend must be specified so the statistician can determine if this trend can be detected.

The first requirement will be assessed for several of the indicators as described above so that variability components can be used to evaluate performance. Some indicator groups are developing variance estimates through historical data, rather than going through the expense and time of a pilot study. Some indicators may have problems with remeasurement or temporal variability that need to be included in the assessment. Some indicator groups are evaluating these points to determine what variance component estimates are most important to determine in the FY91 field season.

The second requirement is also in development. Indicator groups are evaluating their indicators and reviewing their previous work in indicator development to determine ecologically significant trends against which their indicators can be compared.

By the start of the FY91 season, most of the first requirement and all of the second should be completed. By fall of 1991, all of the variance components for the indicators should either be estimated or designated for future study. This will permit the full evaluation of current and future indicators in the EMAP context.

5.4.4 Evaluation of Subplot Size

The evaluation of optimal numbers of plots, subplots, and observations within subplots using the modifications of formulas from Cochran (1977) generates a certain number of subplots as optimal. However, since the subplots can be altered in size, plots could be enlarged instead of altering the plot geometry and adding more subplots. This possibility is relevant because some indicator groups are concerned that the subplots are too small. Also, these numbers must be evaluated carefully since multiple indicators are being studied, and the formulas are designed to generate optimal numbers for computing mean values.

The vertical vegetation structure and PAR indicator groups have expressed concerns that they need to cover a larger area to capture the spatial heterogeneity of the sampling unit and to achieve spatial stability. Since both indicators were sampled on a grid in each subplot, it is anticipated that spatial heterogeneity will be examined as part of this year's analyses. This may allow FHM planners to determine whether or not larger study areas are necessary for these indicators.

Furthermore, the Tier 1 landscape characterization analyses may also allow examination of this question. One important consideration is that Tier 2 sampling not measure anything that can be ascertained at the Tier 1 level for less money. If it turns out that the spatial scales of interest for these indicators are large enough to analyze at Tier 1, then these indicators need not be concerned with collecting that component of the indicator at the field plot level. Instead, it can be determined using remote-sensing and GIS techniques during Tier 1 landscape characterization.

6 STRATEGY FOR STATISTICAL ESTIMATION AND ANALYSIS

6.1 INTRODUCTION

The strategy for the development of the statistical structure for data collection, as well as the strategy for indicator development, has been discussed in the preceding sections. Measurements taken in the field or analyzed in a laboratory can be translated into indicators of aspects of forest condition. But to assess the current status and extent and the observed changes or trends in the data properly, one must be able to estimate these indicators with known confidence. This section will discuss statistical procedures envisioned for these analyses.

The Forest Health Monitoring (FHM) staff will not conduct all research, either ongoing or proposed, for the following topics. EMAP has a cross-cutting program in statistics and design, and the staff of the EMAP-Statistics and Design Coordination group is taking the lead in researching and addressing many of these topics. Furthermore, EMAP-Statistics and Design has cooperative agreements with university statisticians who are developing key pieces of this work. Other resource groups in EMAP and the USFS Rocky Mountain Forest Experiment Station are also working on these problems. Areas in which FHM will concentrate have been discussed in Sections 4 and 5. The incorporation of biological models is discussed in Section 7.

6.2 STATUS AND EXTENT

Graphical displays and descriptive statistics will be used to represent status and extent of current resources. It has been shown that GIS maps displaying extent and spatial pattern can be created using the kind of data that will be collected (Church et al. 1989). Estimates of proportions of the population occurring in various categories will utilize the cumulative distribution function (cdf). The cdf is an important tool in the examination of regional data (Linthurst et al. 1986; Church et al. 1989) and will be used by FHM.

In addition, parametric (model-based) estimation techniques will be evaluated to determine if alternative approaches might be useful. Spatial behavior on a regional scale needs to be addressed, and approaches to this problem will be studied. Special analyses may be appropriate for specific subpopulations. Methods must be developed to deal with measurement error, deconvolution of extraneous variability, and response error.

An important point to address is overlap with current estimates of extent performed by the Forest Inventory and Analysis (FIA) program. The FIA uses probability-based sampling methods with appropriate sampling theory estimators. Furthermore, the FIA has a more dense network of sample sites than EMAP-Forests. Hence, it is unnecessary to duplicate FIA work and make estimates of the same variables because the FIA estimates will have better precision. However, FHM will need to collect the same information as the FIA does to integrate more effectively with the FIA and to calculate any indicators that require some of the FIA's measurements. For example, FHM may use composite estimators to combine the two estimates.

6.2.1 Sampling Theory Estimators

The cdf for a set of univariate data will be generated by using the Horvitz-Thompson (HT) estimation formulas (Horvitz and Thompson 1952). Descriptive statistics (e.g., totals, means, medians, standard deviations, and quantiles) will also be generated by using these formulas. The HT formulas allow estimation of descriptive statistics from any statistical design that is probability-based. The only requirement for estimation is the specification of the inclusion probabilities for the sample data. These inclusion probabilities are obtainable for any probability sample on a statistical framework. The EMAP statistical designs will be restricted to probability-based designs so that the HT formulas can always be used.

In the HT estimation of a total and the variance of the total, two kinds of inclusion probabilities are needed. First and second order inclusion probabilities must be generated. First order inclusion probabilities are the probabilities with which the individual sampling units are included in the sample. These first order inclusion probabilities must be known for each sampling unit included in the actual sample, and these should be generated at the time of sample selection and archived into the data bases (see Section 10). Since these inclusion probabilities will be needed for all analyses that use estimators from sampling theory, they must be available, along with the sampling-unit-level data. These first order inclusion probabilities will be designated by the symbol π_i, referring to the inclusion probability for the i^{th} sampling unit.

Second order inclusion probabilities are pairwise inclusion probabilities. They are the probabilities with which two different sampling units are simultaneously included in the same sample. These are typically denoted as π_{ij}, referring to the probability of including both sampling units i and j in the sample. The design features specific to the ecosystem are needed to determine the π_{ij}. The design features include elements such as sample size and information on the specific strata or clusters in which sampling units i and j fall. That information must be carried along with the data so that use of the data is uncomplicated. The statisticians will work with the information management staff to decide how best to store these data for optimal data utility and storage.

Estimation formulas are simplified by the use of weights rather than inclusion probabilities (Overton 1987), using the notations:

$w_i = 1 / \Pi_i$ and

$w_{ij} = 1 / \Pi_{ij}$

In practice it has been found to be more convenient to store the weights with the data rather than the inclusion probabilities. Using weights instead of inclusion probabilities, the HT formulas may be written as:

$$\hat{T}_y = \Sigma_i w_i y_i$$

$$\hat{V}(\hat{T}_y) = \Sigma_i y_i^2 w_i (w_i - 1) + \Sigma\Sigma_{i \neq j} y_i y_j (w_i w_j - w_{ij})$$

where y is any measured characteristic, and $\hat{T}_y$ is the true total of that characteristic over the population or any specified subpopulation. Estimates over a specified subpopulation are generated by restricting the above sums to the set of sampling units that represent that subpopulation.

The total is estimated as above. If the mean is desired instead, it can be estimated by dividing $\hat{T}_y$ by N, the number of units (or total areal extent, depending on the variable) in the population or subpopulation. If N is unknown, it may be estimated by setting y_i = 1 in the above equations to obtain:

$$\hat{N} = \Sigma_i w_i$$

$$\hat{V}(\hat{N}) = \Sigma_i w_i (w_i - 1) + \Sigma_i \Sigma_{j \neq i} (w_i w_j - w_{ij})$$

Estimators of proportions are obtained by calculating the total $\hat{T}_y$ using variables that only have the values 0 and 1. To estimate the total number of units possessing attribute A, set $y_i = 1$ if the sample unit has attribute A and set $y_i = 0$ otherwise. Then the estimate of the proportion possessing attribute A is given by:

$$\hat{P} = \hat{T}_y / N$$

$$\hat{V}(\hat{P}_y) = \hat{V}(\hat{T}_y) / N^2$$

The variance estimator given previously is statistically unbiased if all second order inclusion probabilities are known exactly. But design features may require the estimation of the joint inclusion probabilities. In such a case, the approximation developed by Overton (1987) will usually be applied. It has been shown that a convenient computational form of this estimate for Tier 1 resources is:

$$w_{ij} = [2nw_i\ w_j - w_i - w_j] / [2\ (n-1)]$$

This approximation has been shown in simulation studies (Overton and Stehman 1987; Stehman and Overton 1987a,b) to perform well in stratified probability sampling.

Estimation for Tier 2 resources will still use the HT estimation formulas, but the joint inclusion probabilities are more complex because they represent the sampling process at both tiers. Methods for the computation of these joint inclusion probabilities have been developed for similar multiple-tiered probability samples (Overton 1987). Under the current design concept of EMAP-Forests, there will be exactly one Tier 2 sample from each Tier 1 characterization hexagon. A uniform distribution will be used to select the sample site, a factor that will simplify the calculation for the joint inclusion probabilities.

6.2.2 Cumulative Distribution Functions

A general characterization of populations is also obtainable using the cdf for any variable y (see Figure 6.1). The weights for the sampling units are essential for the appropriate calculation of the cdf. Any point on the cdf can be thought of as representing the proportion of forests having values of the variable that are less than or equal to a specific value of y. The cdf is then the graph of these proportions as y ranges over all the values seen in the sample. The proportion for any value of y is calculated by using the weights (see Section 6.2.1).

Confidence bounds on the cdf of a proportion of numbers of sampling units may be provided by exact binomial bounds. Binomial bounds, which will give two-sided confidence regions, can be used only if the inclusion probabilities are all equal. Otherwise, it will be more difficult to calculate confidence bounds, and it may be necessary to use ratio variances for the confidence bounds.

Under the current EMAP-Forests design concept, the inclusion probabilities across a region would all be approximately equal; therefore, the binomial bounds could be used as an approximate solution. Multiple regions could be incorporated by treating the cdf as a combination of a fixed number of binomial proportions.

In cases that do not meet the above specifications, EMAP-Statistics and Design recommends confidence bounds on the one-sided distributions of numbers, similar to those used in the National Lake Survey (Overton 1985), with ascending or descending analyses being used depending on the variable.

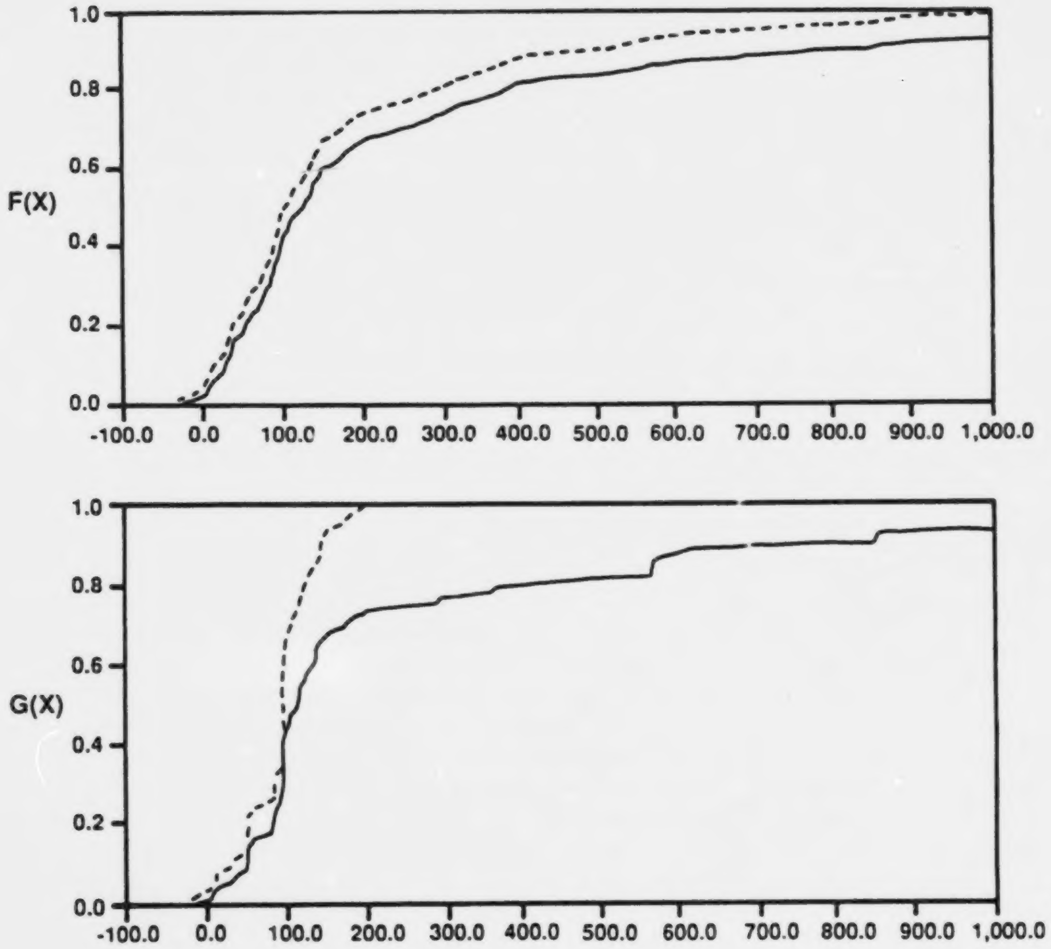


Figure 6.1. Example of estimated distribution plots with upper confidence bounds, generated both as numbers (upper plot) and area (lower plot) (Linthurst et al. 1986).

6.2.3 Model-Based Estimation Techniques

Alternatives to the HT estimators should be studied to ascertain their relative efficiency and power. Methods using auxiliary data to strengthen the estimate of status or extent might prove more effective in some cases. Specifically, if there is not a detectible trend in the variable, it may be feasible to utilize past data from the same sites to develop a more powerful estimator of status. For example, the James-Stein estimator uses related auxiliary data to produce an estimate with improved precision. The FS has started looking at the James-Stein estimator with regard to certain FIA data, and FHM personnel will work with the FS to examine the utility of such an estimator in the EMAP setting. A possibility that has been suggested for trend detection is an estimator based on the exponentially-weighted moving average.

6.2.4 Spatial Patterns

Data collected in the FHM program will be associated with a particular spatial location. Although the confidentiality of the data is crucial, general information about the location of the plots can be used in analyses without compromising that confidentiality. In particular, under the current design concept of one plot per Tier 1 characterization hexagon, the hexagon identification number would provide sufficient information for spatial pattern analysis without jeopardizing the confidentiality of the site location. Given that the plot is located within a 40 km^2 hexagon, stand dynamics and topographical data may also be usable without compromising the plot location.

Another consideration is the scale of the phenomena to be measured. This cannot be determined by the statistician but must be determined by the scientists studying the forest ecosystems. Determination of key spatial scale features for monitoring the condition of forest ecosystems would then provide valuable guidance to the developers of the design. After the design is fixed, spatial characterizations may be limited by features of the design. Choice of density and size of the Tier 1 landscape characterization hexagons should be tied to the scale of the phenomena that are to be measured.

Visual presentation is perhaps the most important method of examining spatial patterns. More sophisticated methods cannot be easily applied without using some exploratory graphical methods first. A number of cartographic techniques are available for the graphical presentation of data. Spatially continuous or nearly continuous data (e.g., synoptic data) can be represented either as a contour surface in three dimensions or drawn using contour lines in two dimensions. Shading, color, and isopleths are all popular ways of representing a third dimension on a two-dimensional printout. Another alternative is the use of a symbol or color to illustrate the magnitude of a variable at a specific point on a map.

Visual displays encounter two problems. First, these techniques do not usually take into account the differing inclusion probabilities that different data points may have. The FHM data represented in this way must use techniques that will display the data using the population weights. Second, visual presentations may require a smoothing procedure to obscure the sampling unit locations and protect the confidentiality of the data. This is not an issue if the scale of the map is coarse enough.

There are other ways of examining spatial pattern. A geostatistical approach that employs some version of kriging (Ripley 1981) may be useful when examining regional gradients or changes in regional gradients. Adaptive splines (Wahba 1990) or random field theory (Ripley 1981) may be useful alternatives to kriging.

6.2.5 Subpopulation Analyses

Another method of examining spatial patterns is through subpopulation analyses. The EMAP design allows for inference on any subset of data that can be described through the attributes of the sample or population. Inferences on any subpopulation are obtained by applying the HT estimation formulas to the appropriate subsample of the data. The same analyses can be generated for a subpopulation as for the population as a whole. Subpopulation analyses can also be used to examine spatial pattern. Regional differences can be expressed by subsetting the population into regions and examining the population distributions of the selected subsets. EMAP-Statistics and Design is working on several ways to analyze and compare distributions. A number of these methods use the cdf.

6.2.6 Deconvolution

If the measurements used to calculate an indicator have appreciable variability due to spatial or temporal variation, then the estimator of the cdf may have bias in the tails (Overton 1987). Furthermore, other descriptive statistics may have large bias. The apparent effect is to increase the system variability. The cdf of the observed data is not the desired cdf but the convolution of the population distribution and the distribution of the extraneous source of variation.

The FHM personnel must recognize extraneous variation, identify this component of variability, and account for it either in the sampling design or in the analyses. In some cases it can be accounted for in confidence limits. "Deconvolution" is defined as the process of actually removing the excess variation from the data (Church et al. 1989). This process is undertaken to eliminate bias in the cdf and to correct the statistics in other analyses. Methodology for deconvolution in the general case is under study by EMAP-Statistics and Design.

Measurement error, which is the accumulation of error in the data collection and analysis process, can also produce biases and variance inflation. Proper quality assurance (QA) can lower measurement error and quantify the level of existing measurement error (see Section 8). Given appropriate QA, the size or relative size of the measurement error can be estimated and incorporated into statistical analyses by using measurement error models.

Another important source of extraneous error is sampling error. In survey sampling, sampling error can be described as a general term for errors in the planning, collection, and processing of data. The problems that are germane to a sampling design such as EMAP are specification error, coverage error, response error, non-response error, and processing error. For the purposes of the FHM program, the issues of response error and processing error fall under the QA issues of instrument error or analytical error.

Specification error and coverage error should be handled before crews go out into the field. Specification error occurs at the planning stage when user needs change or are misinterpreted, the populations of interest are not specified correctly, or the concepts of the program are ill-defined. Coverage error occurs when some units of the population are erroneously omitted, or inappropriate units are inadvertently included. These errors must be eliminated at the planning stages of the project.

Non-response error occurs when some selected sites cannot be sampled (see Section 5.1). If sites that are not sampled differ in some measured way from sites that are sampled, then a bias will be introduced into the data in that measurement. Some of the problems with non-response error can be eliminated by working closely with the FIA. The FIA has worked with private landowners for many years and has built up a relationship of trust that will facilitate site visits. If appreciable non-response error is found or even suspected, sample survey techniques can be called into play to evaluate the size and effect of the non-response bias.

6.3 CHANGE AND TREND

A number of standard statistical techniques are available for the study of change and trend. Methods are also being developed by EMAP-Statistics and Design. Linear models methodology, such as analysis of variance, analysis of covariance, and multiple regression will be used. In order to use these, various assumptions will be formulated and tested regarding spatial and temporal variance components, statistical independence, explanatory variables, the nature of trends, and the pattern of changes. Nonparametric alternatives such as methods that are based on signs of differences or ranks of the data will also be evaluated (Loftis et al. 1989).

EMAP-Statistics and Design has been developing techniques that do not focus on a change in central tendency, but use the cdf to look for other types of distributional behavior. Also, trend detection methods that are specific to the interpenetrating design structure of EMAP are being developed. Specific research includes several methods that account for the effect of temporal correlation to alter the statistical power of trend tests.

EMAP's interpenetrating design will achieve increased power to detect change only after two full cycles of visits have been completed (i.e., after all sites have been visited twice). Repeat visits permit a paired analysis which eliminates one of the components of population variation (Overton et al. 1990). Similarly, the power to detect a continuing trend will increase as more years of data are collected.

6.4 ASSOCIATIONS

Analysis of associations will play a key role in the development of the FHM program and is crucial to the EMAP objectives. Due to the complicated nature of the forest ecosystem and the varying levels of measurement error in the measurement of different variables, it will take time and extensive statistical analysis to develop some of the indicators for the program. The traditional statistical techniques have primarily looked at linear components of behavior. However, recent developments in statistics such as projection pursuit analysis (Friedman 1987) and sliced inverse regression (Li 1989) may permit the evaluation of nonlinear relationships as well.

In addition, the analysis of associations in the EMAP context has two problems that distinguish it from analysis of associations in the standard statistical context. Unequal inclusion probabilities can complicate data analyses, and the observational nature of the data puts limitations on the inferences to be drawn from the statistical analyses.

6.4.1 Consequences of Unequal Inclusion Probabilities

When the data collected are associated with different inclusion probabilities, this must be accounted for in the statistical analyses. This is typically done by weighing the observations using the inverses of the inclusion probabilities. This is one reason why the EMAP design attempts to eliminate variable weights, except among resource strata.

If the weights are all the same within an individual stratum, simple unweighted analyses are all that are needed within that stratum. Furthermore, if the weights within a stratum are only approximately equal, then it has been shown (DuMouchel and Duncan 1983) that simple unweighted analyses are generally sufficient. The same authors also developed a methodology for assessing when unweighted analyses would be preferable to weighted analyses.

A more complicated problem arises if different strata have different functional forms for the regression. In such a case it can be argued that the analysis of the combined data is meaningless. A regression equation developed in such a situation may have applicability to none of the actual population. This problem of course does not arise if the strata are not to be analyzed together. On the other hand, if there is an important reason to combine such strata, the analysis can still be performed. But the weights and the results of the analysis must be carefully considered.

An alternative in such a case may be the use of meta-analysis methodologies (Hedges and Olkin 1985) to examine the overall behavior of the entire set of strata for general hypothesis evaluation. Meta-analysis techniques have not been applied to forest ecosystem problems as yet. However, FHM will have extensive datasets for the evaluation of these methods.

An important problem caused by unequal weights is the graphical presentation of the data. Scatterplots are a basic tool of exploratory data analysis, but a way to make the number of points in each of the stratum samples proportional to the population numbers is required. One proposed FHM method is to plot circles and make the radius of each circle proportional to the square root of the weight. In this way, the area presented to the viewer will effectively represent the appropriate relative size of the population.

6.4.2 Consequences of Using Observational Data

Hypothesis testing in the context of the EMAP program also presents problems. Schreuder and McClure (1991) discuss this in the context of the FIA program. Data collected will be observational data, not experimental data. Hypothesis tests performed on observational data are the same as those on data from planned experiments, but the problem is seen in the inferences that can be drawn from observational data. Causality is difficult to establish from observational data due to the large number of uncontrolled factors. Causality is proven by formal experiments, while observational studies can only establish associations. On the other hand, associations seen on regional or national scales can provide powerful associations that might be difficult to see in individual study sites. The associations developed from FHM data will need to be evaluated and then tested or validated in other settings such as controlled experiments.

6.5 METHODS FOR INTEGRATION OF INFORMATION

The FHM program will require data other than those measurements collected at the Tier 2 sites. And the FHM program can benefit from work with other programs that have studied related areas and ecosystems.

6.5.1 Other EMAP Resources

In addition to data collected at the Tier 2 sites, the FHM program will need information on auxiliary data. The photointerpretation work by EMAP-Landscape Characterization will provide essential Tier 1 data on landscape processes. Under the current design concept of one Tier 2 site within each Tier 1 hexagon, it is statistically straightforward to associate landscape process data with the Tier 2 data. Decisions on level and scope of landscape characterization must be made by the appropriate people. But whether it is decided to use landscape information for the area around the plot, the watershed containing the plot, or the entire hexagon, those data can be directly associated with Tier 2 data that have been aggregated to the plot level.

The FHM personnel will also need data from EMAP-Air and Deposition. Data on wet and dry deposition, climate, and weather will be required for many analyses. These data will be used as essential covariates in regressions and analysis of variance in order to remove variation in the measurements and indicators that is associated with climatic and meteorological data. Problems with association in this case are related to the measurement error of the estimates.

It is prohibitively expensive to monitor every site for everything of interest; therefore, data from EMAP-Air and Deposition will be estimated from monitoring networks. The sizes of the system measurement errors for their variables will be crucial in determining how to use the variables. If these data have small measurement error, the variables will be useful covariates. If the measurement error is not negligible but reasonably small, measurement error models may be required to correct for the variability in these data. If the measurement error is too large, these data will not be usable in the analyses.

Data from other resource groups in EMAP will also be used. Data on nearby wetlands condition or the management practices of nearby agroecosystems may elucidate ecosystem behavior across EMAP boundaries. Forest soil data may assist in the quantification of wetlands or surface water conditions. To use such data, each EMAP resource group must develop a statistical design that is based on the overall EMAP design concept so that links among resource groups may be made for statistical analyses.

Areas such as forested wetlands, which may be classified into one of two different ecosystems, may be of interest to more than one resource group. In such a case, it may be feasible to build a cooperative effort among EMAP resource groups and sample the features of interest to each group.

6.5.2 FIA Data

Under the current design concept, the EMAP-Forests program will be based on a random subset of the FIA forest inventory network. This will allow EMAP-Forests to link into the FIA network. Mechanisms are being developed to extrapolate EMAP-Forests results to the larger FIA network and to use FIA estimates to help the EMAP-Forests analyses. Methods for combining estimates are mentioned in Section 5.

6.5.3 "Encountered" Data

The most difficult area is the integration of "encountered" data, data that are acquired without using a statistical design (Overton 1990). Large quantities of non-random or haphazard data are available which will be difficult to integrate into the FHM framework due to the lack of a statistical framework for their collection. This problem is being examined by EMAP-Statistics and Design. Several possible approaches involve subsetting or clustering the non-random samples into compartments that would parallel the FHM statistical framework.

7 STRATEGY FOR ASSESSMENTS

7.1 INTRODUCTION TO ASSESSMENT

Assessment is a process by which data are converted into useful information. An assessment strategy describes how knowledgeable analysts will organize, synthesize, and interpret data in order to simplify data, test for change and differences, generate hypotheses, determine the consequences of observations, and evaluate the uncertainty of conclusions (NRC 1990a). As the prime points of contact with society, it is the assessors' role to ascertain social needs and to translate them into guidance for reporting. Since assessment requires organization and synthesis of data, assessors have a role in linking pieces of the program together. Finally, assessors have a role in exploring techniques and developing knowledge that will improve interpretations.

There are many challenges to formulating an assessment strategy. Environmental problems are becoming increasingly complex and scientists have limited understanding of them. The assessment strategy has to address many public, regulatory, and management concerns about forests: atmospheric deposition, nonpoint pollution, climate change, deforestation, and biological diversity. Data and models will be used in different ways to define and interpret ecological condition and to evaluate the results of programs and predictive models (Linthurst 1990). Coordination is needed to achieve these assessment objectives within the multi-tiered, multi-regional, and multi-agency framework of forest health monitoring (FHM) and within the EPA risk assessment framework (see Section 2).

The primary, short-term objectives of EMAP-Forests assessments are to produce periodic statistical summaries, interpretive reports, and integrated assessments that address the regional status and trends of the nation's forests in relation to human-induced stresses (see Section 11). The long-term FHM assessment strategy will have to evolve to maintain consistency with the overall EMAP program (see Section 1). The FHM personnel can help to determine overall, long-term goals by taking an active role in client identification, question definition, and evaluation of user responses.

7.2 STATUS OF FOREST ASSESSMENTS

This section is a first attempt to describe an assessment strategy for FHM. To date, the general EMAP assessment strategy (see Section 2) has been the point of departure for design decisions. This section reviews what has been done to implement the general strategy in the particular case of forests.

7.2.1 The Assessment Paradigm

Environmental concerns identified by EMAP-Forests include sustainability, productivity, aesthetics, diversity, extent, utilization, contamination, and quality. These concerns relate to the environmentalist paradigm described in Section 2. These eight concerns will be addressed by assessment endpoints for the abiotic (soil, water, and air) and biotic (vegetation, animals) components of forest ecosystems.

A peer review of the indicator strategy in May 1990 by the EPA Science Advisory Board endorsed the general approach to forest assessment, commended the progress made, and indicated that the necessary linkages between environmental concerns and measurements are possible to define. Since that time, most of EMAP-Forests' assessment resources have been devoted to a field test of measurement systems and to an example statistical summary. In December 1990, attention was again shifted back to the assessment process.

Figure 7.1 summarizes the current status of the assessment framework for forests, considering what is in an ecosystem (components) and how one may view an ecosystem (concerns). Despite apparent holes in the framework, the progress to date is encouraging. Traditional concerns such as contamination, utilization, extent, and productivity can be reliably assessed in most situations. But concerns for sustainability, aesthetics, diversity, and quality are not currently amenable to reliable assessments.

7.2.2 Other Assessment Activities

An example statistical summary (Riitters et al. 1990b) was prepared to demonstrate the EMAP statistical assessment framework in the context of forests. The example report did not consider many indicators that could be included in such a report, nor did it report the possibility of testing statistical correlations among indicators.

Data collected during the 1990 field season by the Forest Service (FS) in the six New England states (Miller-Weeks and

ENVIRONMENTAL VALUE	RESOURCE TYPE				
	Soil	Water	Air	Vegetation	Animals
Sustainability	☐	☐	—	☐	☐
Productivity	—	—	—	■	■
Aesthetics	☐	☐	■	☐	☐
Diversity	—	—	—	▨	▨
Extent	■	■	—	■	▨
Utilization	—	—	—	■	■
Contamination	■	—	■	■	■
Quality	☐	—	▨	☐	☐

ASSESSMENT RELIABILITY

■ High ▨ Moderate ☐ Low — Not Applicable

Figure 7.1. Current status of assessment framework for forests.

Gagnon 1990) are being analyzed with a view towards producing a statistical summary. Details of the interagency summary are currently being decided. EMAP-Forests is contributing statistical summaries of meteorological, air quality, and pollution deposition data to this effort.

Data collected by the EPA and the FS in New England and Virginia during the 1990 field season are being analyzed to explore statistical relationships among some indicators of forest condition (Palmer et. al. 1990). Ecosystem models have been proposed to assist interpretation, but their possible applications have not been specified in detail. Individual analysts are developing procedures to summarize and interpret various subsets of forest indicator data (e.g., soil measurements and observations of visual symptoms). Linkages between environmental concerns and indicators have not been specified in detail.

Prototypes of certain auxiliary (off-frame) data bases have been acquired to evaluate their potential utility. These include portions of the Soil Conservation Service (SCS) STATSGO data base, the National Oceanic and Atmospheric Administration (NOAA) TD-3220 data base, and the Forest Service-Forest Inventory and Analysis (FIA) data base.

7.3 A STRATEGY FOR FHM ASSESSMENTS

A forest ecosystem may be defined (after Waring and Schlesinger 1985) to include living organisms and non-living substrates from the top of the canopy to the lowest soil layers affected by biotic processes. They are open systems that exchange energy and materials with other systems. Systems theory suggests that forests can be modeled as collections of compartments and fluxes of materials and energy. Hierarchy theory suggests that the model scales can be linked and that models to interpret indicators should be consistent with the scales of measurements. These considerations will have much to do with a modeling strategy for FHM assessments.

A conceptual model of the forest ecosystem (Figure 7.2) suggests the potential biological scope of inquiry of forest assessments. Scientists can choose to represent and model these components and processes at different scales for different purposes. Ideally, models for biological interpretation of monitoring data would be specified at the same scales as the various indicators that are the main focus of assessment (O'Neill 1988). Consideration of linkages among scales is also necessary because some measurements may be made at finer scales and because the context for assessment is always given by a higher level in the hierarchy. To implement the environmentalist paradigm, ecosystem models such as these will have to be augmented to reflect human interactions with the environment.

Levins (1966) has suggested that any single model can emphasize only two of the three characteristics of generality, precision, and realism. The trade-off for monitoring is that models for descriptive monitoring emphasize generality while those for interpretive assessments emphasize precision. Modeling to meet EMAP's primary Tier 1 and Tier 2 assessment goals has these objectives:

- Summarize current status, extent, and trends of forest condition.
- Detect unusual situations of forest condition.
- Summarize correlative evidence linking those situations with man-induced stresses.
- Relate forest condition to environmental values. Several types of models are defined here:

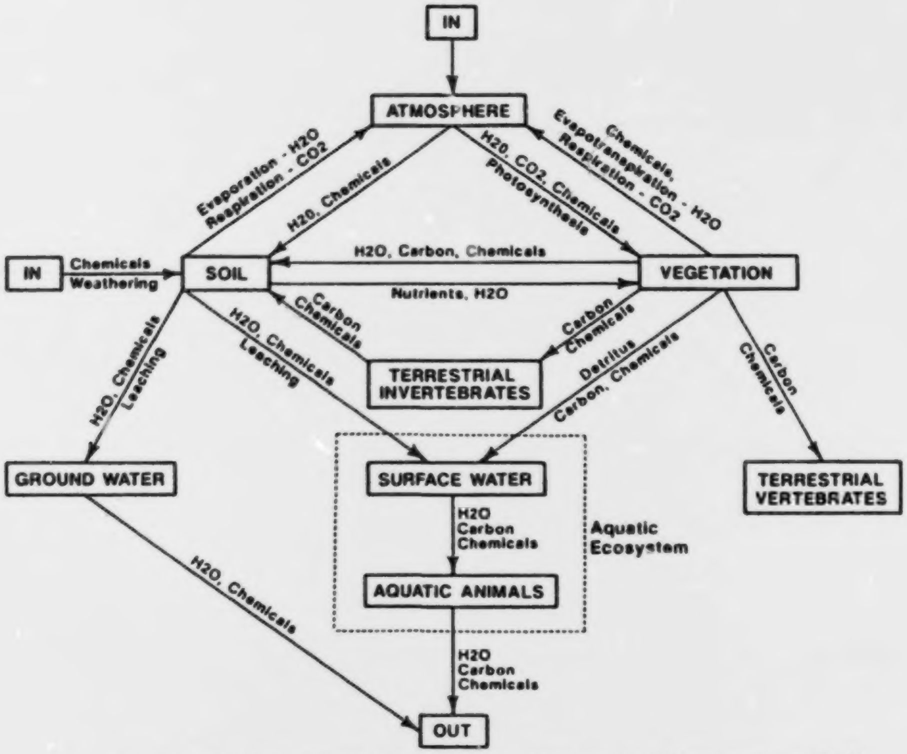

IN
ATMOSPHERE
Evaporation - H2O
Respiration - CO2
H2O, Chemicals
H2O, CO2, Chemicals
Photosynthesis
Chemicals,
Evapotranspiration - H2O
Respiration - CO2
IN
Chemicals
Weathering
SOIL
H2O, Carbon, Chemicals
Nutrients, H2O
VEGETATION
Carbon
Chemicals
Carbon
Chemicals
TERRESTRIAL INVERTEBRATES
H2O, Chemicals
Leaching
H2O, Chemicals
Leaching
Detritus
Carbon, Chemicals
Carbon
Chemicals
GROUND WATER
SURFACE WATER
TERRESTRIAL VERTEBRATES
H2O
Carbon
Chemicals
Aquatic
Ecosystem
AQUATIC ANIMALS
H2O, Chemicals
H2O
Carbon
Chemicals
OUT

Figure 7.2. Conceptual forest ecosystem model (Anonymous 1988).

Indicator -- Indicator models define relationships between measurements and indicators, and hence endpoints.

Classification -- Classification models define relationships between indicators and axes of the classification schemes.

Index -- Multiple indicator models define index values from sets of indicators.

Interpretive -- Interpretive models define relationships between indicators and measurements or auxiliary data not included in the above model types.

Valuation -- Valuation models are objective functions that define relationships between indicators or indices and environmental values.

For a given scale of monitoring, linkages to finer scale patterns and processes are defined by indicator models, and linkages to higher levels are defined by valuation models. Classification and index models are only defined at the chosen scale for monitoring and interpretive models are preferably defined at that scale also. In this scheme, descriptions and summaries of status and trends of condition are based on indicator, classification, and index models. Linkages to environmental concerns utilize valuation models to define policy-relevance of status and trends. Exploratory analyses and correlations utilize interpretive models.

Models defined at scales finer than the monitoring scale are not made explicit in the general assessment strategy because they consider specifics that cannot be resolved by monitoring indicators. Rather, these models are in the realm of Tier 3 and Tier 4 monitoring and research. But as part of the indicator development strategy, Tier 4 models may identify indicators for monitoring at Tiers 1 and 2. They may also identify more detailed measurements to track particular cause and effect relationships for Tier 3 monitoring.

Assessments will utilize these types of models to organize, synthesize, and interpret the data. In a flexible and evolving system, there can be several models of each type, and not all models need be present or in a comparable stage of development. To avoid a chaotic evolution of conceptual models, measurements, and assessments, it is desirable to emphasize model refinement rather than model replacement.

7.3.1 Statistical Assessment Models

Emphasis will be placed on statistical models developed with knowledge of biological processes. Initial applications of these models require simplifications and assumptions that can be modified later (see Section 7.3.2). The description of forest status and trends starts by reducing forest measurements to a set of values utilizing indicator and/or index models. This is done for each indicator or index for each measurement at each site. In the simplest case, statistical estimation formulas (Section 6) are then applied to these values to provide a regional description of the status and trends of forest condition. In most cases, it will be possible to develop more meaningful regional descriptions by utilizing a classification model to stratify the sample for analysis.

Assuming that a nominal-marginal-subnominal scheme (a valuation model) has been decided for each indicator or index, the spatial and temporal status and trend descriptions can be given in terms of environmental concerns rather than response indicators. The statistical estimation formulas of Section 6 also apply here.

7.3.2 Interpretive Assessment Models

Interpretive modeling may improve upon statistical descriptions by finding and increasing the accuracy of indicator, classification, and index models, by introducing new interpretive models, and by refining valuation models. Interpretive assessments will usually require a changing array of models over time as different environmental concerns and biological phenomena become important. It is expected that interpretive models which prove useful would be incorporated into statistical summaries.

Mechanistic and heuristic models are important modeling approaches. The mechanistic approach would be needed, for example, to estimate quantitatively the specific effects of a specific stress on a specific environmental value. Mechanistic models would also be needed to account for interactions among indicators, and among indicators and space-time, that are not accountable using statistical models alone. The heuristic approach would be needed, for example, to define the best way of representing system behavior in a mechanistic model.

7.3.2.1 Modeling Themes

Model development is needed to:

- Improve statistical descriptions by finding and increasing the accuracy of indicator, classification, and index models.

- Improve interpretations by introducing interpretive models.
- Improve the relevance of all assessments by finding and refining valuation models.

7.3.2.1.1 Indicator, Classification, and Index Models

Statistical assessments can be improved by enhancing the apparent signal of condition. This process incorporates additional data and understanding to produce new indicators or values with more information content than before. The increased information content is evidenced by an increased robustness, perhaps to particular stresses.

A simplified example approach for isolating a signal due to air pollution will be described. This general approach has been used in dendroecological studies (e.g., Graybill 1982; Cook 1987; Kincaid and Nash 1988; Zahner et al. 1989) and in assessments of soil (e.g., Bouma 1989) and water quality (e.g., Radford and West 1986). More complex formulations are possible.

Let $I = f(F) = g(A) + h(P) + e$ [7.1]

where I = a response indicator of forest condition,
F = a set of forest state variables used to construct I,
A = a set of environmental variables affecting the state variables in F,
P = a set of pollution variables affecting the state variables in F,
f, g, and h are functions, and
e = remaining unexplained variation.

Without signal enhancement, associations between indicators would be estimated by the relationships between $f(F)$ and $h(P)$ and tested by reference to e. Signal enhancement is designed to extract $g(A)$ from e, and thereby reduce the "noise" in the association. This is essentially a covariance-type analysis where the covariate is taken to be a generalized function of the environment that partitions the "normal" variation of an indicator.

Distinctions between "normal" and "abnormal" values of an indicator are contextual. For example, an analysis of pollution effects could focus on pollution signals after adjustments for stand dynamics or weather in the covariance function, whereas an analysis of natural versus man-induced stresses might utilize a different formulation. Much more complicated formulations will be required to deal with confounding and correlations among the various explanatory factors that are explored in any analysis.

The "signal enhancement" model is a reason for understanding normal patterns and trends in forest condition, as opposed to developing understanding of mechanisms of abnormal patterns and trends. This model is also a reason for collecting certain "ancillary" data on monitoring sites, that is, data that are used to estimate "normality" rather than the indicators of abnormal response, habitat, exposure, or stress.

The classification schemes become very important when considering these types of models. That a given function I may not have the same meaning for different classifications was alluded to earlier. Stratification of the population to obtain comparable meanings for indicators implies concomitant subsetting for the definitions of the submodels in equation 7.1. This is a problem because it will require more models, but the models for each case should be simpler. In fact, subsetting by classification variables is perhaps a more viable option than developing a single mega-model applicable to all situations.

The classification axes may be thought of as covariates of the type g(A). Variables deemed mandatory from first principles may in fact be handled better via classification. If classifications are based on vegetation composition and soils, they will likely reflect forest and soil development and succession which in turn depend upon biophysical variables. One would expect that soil parent material, and long-term moisture and temperature regimes will be the most important biophysical variables that determine the classification of a given site. With classification, the functions g(A) probably need not consider global geology or climate, only local fluctuations. The importance of local fluctuations should be explored with a good understanding of global trends.

When indicators are refined, the question arises whether or not the indicator still takes on the same meaning at all sites. For example, the same quantitative value of I may imply different conditions in two different resource classes. One way to account for these differences is to consider an analysis of deviations from expectations ("normal condition") as an alternative to an analysis of the indicator values themselves. This would complicate the setting of assessment endpoints but may offer a more realistic regional picture of status and trends.

In the simplest case, using the nomenclature from above, replace the indicator I by the new indicator I^*, where I^* is a function (e.g., a scaled difference or ratio) of the observed indicator and its expectation under "normal" environmental conditions. In other words, I^* is a deviation of I from its expected value that is not explained by ancillary variables and that is scaled in some fashion to make it more comparable among resource classes. The expected value is dynamic because g(A) is dynamic. In this way, normality need not imply an unchanging condition.

With this formulation, it becomes easier to see how statistical expectations from historical trends can be utilized. While expectations for the response indicator I were defined above with reference to process models (i.e., g(A)), statistical expectations based on past experience or spatial pattern can also be used for this purpose. In general application, the current best estimate of unexpected value can be used to adjust response indicator values. New understanding of environmental processes can be introduced into the analysis of change by g(A) which may be a dynamic function over time and may be freely modified for analyses of different types of environmental stresses.

7.3.2.1.2 Interpretive Models

Forest monitoring produces data that can be used to study the forest conditions in an epidemiological framework. The heuristic approach is based on observational data that arise from a cross-sectional sample rather than on experimental data that arise from controlled comparative trials (Fleiss 1973). The absence of randomization severely restricts the testing of mechanisms but does not prevent identification of possible cause and effect relationships (Mosteller and Tukey 1977). An early discussion of the possibilities and approaches is given by Wallace (1978). A good and more recent discussion of possibilities in forest monitoring is given in Schreuder and McClure (1991).

It was mentioned in Section 2 that forest monitoring data can be used to satisfy two of the four NRC (1989) criteria for inferring causality. Measures of correlation and of temporality are typical tools in epidemiology and have already been discussed as part of statistical assessments. This section describes two possible refinements that could be used in interpretive studies, namely "gradient studies" and "fingerprinting". In practice, these techniques are likely to be utilized on an ad hoc basis, for the appropriate epidemiological tool will depend on the particular circumstances.

In situations where a known environmental gradient exists, observational data taken along the gradient can potentially be used to test the association of forest condition with that gradient. For example, Ohmann and Grigal (1990) were able to associate concentrations of sulfur in wood with sulfate deposition by sampling woody tissue along a known sulfate gradient. In other examples, dendroecologists can typically associate ring widths with distance from smelters, ecophyiologists commonly associate tree distribution to temperature and moisture gradients. Gradients can exist in time as well as in space which opens up the possibility of time-series techniques such as intervention analysis, and combined space-time analyses.

"Fingerprinting" (MacCracken and Moses 1982) refers to testing a particular set of observations against the sets of observations that would be expected under various types of stresses. Waring (1990) advocates and describes this approach for diagnosing causes of change in forest ecosystems. Johnson (1988) puts the discussion into a statistical framework that suggests an approach to developing multivariate indicators of condition. Simmleit and Schulten (1989) provide an application of statistical "pattern recognition" for fingerprinting damage symptoms in forest trees. Fingerprinting is a general tool that a knowledgeable analyst will use to build a case for or against a particular cause and effect hypothesis, and many variations on the basic theme are possible.

Mechanistic models to interpret Tier 1 and 2 monitoring data are not readily available. These large-scale and long-term models can be based partly on existing theory but additional work is needed to conceptualize a hierarchical structure that operates at the appropriate scales and that includes linkages to higher- and lower-level processes and scales (O'Neill et. al. 1986). The results of heuristic modeling currently underway can be applied to this conceptual development.

7.3.2.1.3 Valuation Models

An important assessment function is to relate observed changes or possible future scenarios to impacts on society. The first priority is to identify valuation models so that the boundaries of "good" and "bad" condition are identified for any response indicator. But these models should go beyond simple classification of condition. Valuation models and objective functions are needed to quantitatively assess the relationships between a certain value or change of value of a response indicator, and an impact on society. This implies that societal values must be quantified much more specifically than they are now.

This effort can build upon past research in resource economics, especially for environmental values such as "utilization" that are typically measured by a monetary scale. For other environmental values such as "aesthetics" or "sustainability" the metrics are much less clear.

7.3.3 Statistical Regionalization Using Off-frame Data

Regionalization refers to the process of aggregating site-specific data at regional scales using various classification such as political or administrative boundaries and forest or soil types. A focus on classification combined with the use of off-frame data distinguishes statistical regionalization from landscape ecology, although both approaches yield regional answers. These techniques may complement the statistical techniques based on the sample frame (see S ection 4.5). Preliminary reviews of available techniques suggest that post-stratification is the most viable alternative. Other techniques of regionalization such as spatial statistical methods or the extrapolation of intensive research site data have been suggested, but their applications require further development.

EMAP is currently evaluating schemes for combining on- and off-frame data (Overton 1990). The FHM program has additional concerns such as the compatibility of forest area estimates made by different agencies.

7.3.4 Auxiliary Data Bases

Table 7.1 lists some of the data bases that are of primary interest to FHM assessments. They will be used to aid the analysis and interpretation of forest monitoring data, providing unique or supplemental data for:

- Better estimates of the extent of monitored conditions (i.e., extrapolation and interpolation).
- Better interpretation of the status and trends of forest condition (i.e., correlation with environmental stresses).

Preliminary plans for the air quality and atmospheric deposition components of FHM list the atmospheric constituents of interest (Table 7.2). Preliminary plans for the meteorology component of FHM consider extreme events (tornadoes, high wind, hail), drought, freeze, growing season measures, and possibly lightning events.

7.3.5 Uncertainty Estimation

Uncertainty estimation is an integral feature of assessments (Walters and Holling 1990). It is useful to know when a change in a given indicator is small in relation to the uncertainty about the components of the indicator because conclusions on the basis of the available information could be erroneous. Thus, the quality and uncertainty of the data which are collected and reported will be documented as part of assessment reports.

Uncertainty is partly due to imprecision or bias in the measurement system arising from, for example, inconsistent field instrument readings, missing data, unstable analytical stock solutions, or detectability limits. Uncertainty also results from extrapolating sample data to regional populations. Measurement uncertainty can usually be controlled at an acceptable level through the application of a rigorous QA program during all phases of measurements. Uncertainty of extrapolation, on the other hand, is controlled and estimated through application of statistical principles for sampling and aggregating data to describe populations.

Each additional level of sample aggregation adds a degree of uncertainty to the results which is dependent upon the appropriateness of the aggregation scheme. Some of this uncertainty can be reduced by covariance analyses, but the development of an effective and straightforward sample aggregation scheme for each indicator deserves high priority. Such schemes will help to guide the development of the various indicators, the associated uncertainty models, and the interpretive models that will be applied in later analyses.

The statistics to be reported for each variable could include the following:

- Measurement precision, sampling error, and standard errors for population-level estimates, which could be reported as measurement uncertainty, sampling uncertainty, and extrapolation uncertainty.

Table 7.1. Auxiliary Data Bases: Uses, Sources, and Acquisition Intervals.

Data type	Uses	Source	Periodicity
Forest inventory	Regionalization Extrapolation	USFS (RPA)	5-10 yr
Soil inventory	Regionalization Extrapolation	SCS (STATSGO)	10+ yr
Air Quality & deposition	Correlation Interpretation	EPA (EMAP-Air & Deposition)	As needed
Weather	Correlation Interpretation	NOAA	As needed
Pest outbreak surveys	Correlation Interpretation	USFS (FPM)	Event-related
Topography & hydrology	Classification	USGS NASA	10 + yr
Wildlife	Monitoring	FWS	5-10 yr

Table 7.2. Atmospheric Constituents of Interest[a].

Constituent	Sample Frequency	Data Use
Ozone	Continuous (hourly Averages)	regional status and trends
Total deposition:		
Wet deposition[b]	Weekly	regional status and trends
Dry deposition[c]	Weekly	regional status and trends
Cloud/fog deposition[d]	Episode	regional status and trends

[a] From Baumgardner, Shadwick, and Smith. Draft plan for air quality and atmospheric deposition in EMAP-Forests. EPA, Research Triangle Park NC.

[b] Parameters for wet deposition are H^+, NO_3^-, SO_4^{-2}, NH_4^+, Ca^{+2}, Al^{+3}, Mg^{+2}, and Cl^-.

[c] Parameters for dry deposition are total sulfur flux and total nitrogen flux (SO_2, HNO_3, HNO_2, NO_3^-, SO_4^{-2}, and NH_4^+.

[d] Parameters for cloud/fog deposition are the same as for wet deposition. Cloud/fog deposition is limited to areas about cloud base and along some coastal areas.

- Percent of samples above the measurement system detection limit.
- Percent of planned sample size actually obtained (a measurement of completeness of the sample).
- System detection limits and inherent precision at different magnitudes of measurement.
- Ratios of various components of uncertainty.

7.4 STRATEGY ELEMENTS AND GOALS

Report production, infrastructure, and planning are elements of a strategy. For each element, short- and long-term goals are suggested in this section.

7.4.1 Report Production

The long-term goals are to produce a multi-agency interpretive report on forest condition in 1993, and to participate in an EMAP integrated assessment in 1994 or 1995. In the short-term, reports can be produced as data become available, determined mainly by progress in implementation and interagency cooperation. It is expected that EMAP-Forests will develop regional statistical assessments with the FS starting in 1991 or 1992, and multi-agency, national statistical assessments by 1995 when implementation is completed nationally. In 1991, EMAP-Forests will assist the EMAP-Integration and Assessment Project in preparing an example interpretive report based on data collected in the 1990 field season.

7.4.2 Infrastructure

National leaders will be responsible for each combination of environmental concern and resource type (see Table 7.1). These leaders are scientists and are primarily responsible for defining response indicators and measurements. They also assist in defining assessment endpoints for their response indicators.

A national coordination group will also be identified. The national group will be a small interagency group, including the EPA, the FS, and others. This group will be responsible for defining environmental concerns, resource issues, and priorities of concern. In cooperation with scientists, they will also define assessment endpoints from response indicators. Finally, the national coordination group will be concerned with the procedures and scheduling of analyses and reports.

Short-term goals include identification of regional and national leaders and their responsibilities. Longer-term goals include closer integration of EMAP-Forests assessment teams with the larger EMAP assessment team. EMAP-Forests teams could include personnel from other resource groups to facilitate the later merging of efforts into one organizational structure.

A multi-agency outreach program will be emphasized rather than a strategy of accumulating a large number of in-house analysts. This strategy will require that data bases be readily available and easily accessible to many analysts around the country. The Forest Information Center (FIC) described in section 10 is an important component of the assessment infrastructure.

7.4.3 Planning

In FY91, much of the assessment effort will be devoted to preparing parts of the multi-agency monitoring plan scheduled for February 1992. As part of preparing the research plan, EMAP-Forests will:

- Identify the various pieces of the infrastructure described earlier.

- Lead an effort to reach out to other agencies for participation in assessments.
- Conduct studies, workshops, and reviews aimed at better definition of environmental concerns and assessment endpoints and of analytical methods for organizing, summarizing, and interpreting data.
- Develop plans for integrating with the EPA risk assessment process.

8. QUALITY ASSURANCE PROGRAM

8.1 INTRODUCTION

The underlying reason for quality assurance (QA) is to provide confidence in the environmental data and statistics generated by the Forest Health Monitoring (FHM) participants. Hence, the mission of QA in FHM is to ensure that all FHM data and statistical products are of documented and sufficient quality to satisfy the needs of data users, policy makers, and the public.

EMAP will operate within the guidelines of the EPA's Quality Assurance Management Staff (QAMS). Comprehensive QA techniques will be employed to ensure the quality and usefulness of the data. The overall policies, organization objectives, and functional responsibilities designed to achieve data quality goals for FHM activities are described in this section. Other topics discussed in this section include the process of establishing data quality objectives (DQOs), total quality management, documentation, and reporting.

8.2 QUALITY ASSURANCE POLICY

EPA Order 5360.1, "Policy and Program Requirements to Implement the Quality Assurance Program" was issued in April 1984, to help ensure that all decisions made by the EPA are supported by a valid data base. This goal necessitates the integration of QA into all data collection activities.

EMAP policy, which requires integral QA components for all data collection and processing activities, will follow this approach. A QA program to ensure that all data are of known and documented quality will be established. Resources commensurate with the goals and objectives of the EMAP program will be made available to the QA staff to accomplish these goals.

EMAP is a major environmental data collection effort and an emerging program. The overall QA program for EMAP is described in the Quality Assurance Program Plan (QAPP) (Graves 1990; EPA 1987). As the processes in EMAP are refined and optimized, the QAPP will be modified to reflect these improvements. The specific FHM QA program will be detailed in a Quality Assurance Project Plan (QAPjP) that must be prepared prior to full implementation of the monitoring program.

8.3 TOTAL QUALITY MANAGEMENT

8.3.1 Introduction

Total quality management (TQM) is a process of continuous improvement and innovation led by the program directors in which management philosophy, planning, and operating methodology are fully integrated. EMAP program directors must be committed to quality improvement in all aspects of the program. This is a relatively new operational framework within the EPA which concentrates on providing a service to the internal or external client (customer) by improving the systems within which all work is performed. This primary tenet is directed toward obtaining customer satisfaction, a tenet to which QA is directly and intrinsically linked (Figure 8.1).

8.3.2 TQM Philosophy

The TQM philosophy is participatory in nature; it is aimed at achieving total employee commitment to quality. This commitment must span all levels of EMAP, from the program directors to the scientists and technicians conducting basic implementation and support activities. The EMAP program directors must be committed to the TQM approach and its integration into their day-to-day management activities. This means that EMAP personnel at every level must be committed to the management of all aspects

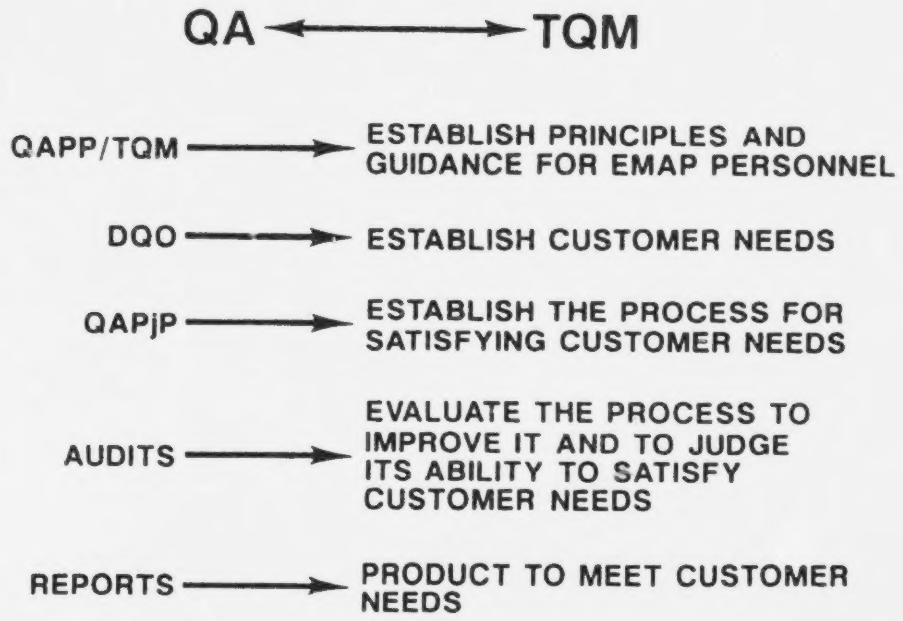

QA ←→ TQM
QAPP/TQM → ESTABLISH PRINCIPLES AND GUIDANCE FOR EMAP PERSONNEL
DQO → ESTABLISH CUSTOMER NEEDS
QAPjP → ESTABLISH THE PROCESS FOR SATISFYING CUSTOMER NEEDS
AUDITS → EVALUATE THE PROCESS TO IMPROVE IT AND TO JUDGE ITS ABILITY TO SATISFY CUSTOMER NEEDS
REPORTS → PRODUCT TO MEET CUSTOMER NEEDS

Figure 8.1. Relationships between quality assurance and total quality management's primary tenet "customer satisfaction."

of the quality of the output, product, or service (Figure 8.2).

Data collection phases, from sample collection to analysis, can be viewed as a series of inputs and outputs where quality is directly affected by TQM applications.

All EMAP participants must understand the goals of the program and make contributions to the decision-making processes that are pertinent to their roles. In summary, TQM focuses on:

- Client identification - All "clients" must be identified and brought into the process to articulate their requirements at each program level in terms of operations, resource needs, and functions. Effective and continuous communications of client requirements must be maintained among the large network of participants.
- Standards and Performance - Arbitrary quotas and goals must be replaced by standards and measures of performance which are proactive rather than reactive.
- Commitment by Program Directors - TQM requires commitment, engagement, direction, and support from program directors to succeed. This commitment is exemplified during training by establishing procedures and policies that foster a TQM "culture."
- Employee Recognition - Recognition of the importance of all EMAP participants is a key ingredient to the success of TQM. Criteria and mechanisms for employee recognition are essential. They emphasize human aspects such as effort, creativity, and achievement. These criteria serve as

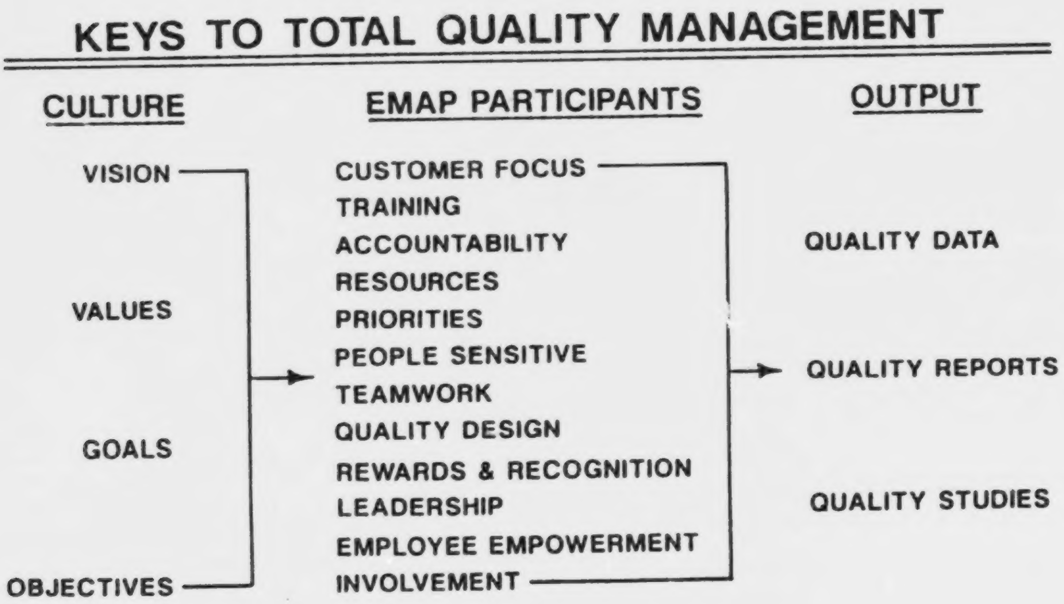

KEYS TO TOTAL QUALITY MANAGEMENT
CULTURE
EMAP PARTICIPANTS
OUTPUT
VISION
VALUES
GOALS
OBJECTIVES
CUSTOMER FOCUS
TRAINING
ACCOUNTABILITY
RESOURCES
PRIORITIES
PEOPLE SENSITIVE
TEAMWORK
QUALITY DESIGN
REWARDS & RECOGNITION
LEADERSHIP
EMPLOYEE EMPOWERMENT
INVOLVEMENT
QUALITY DATA
QUALITY REPORTS
QUALITY STUDIES

Figure 8.2. EMAP commitment to total quality management.

benchmarks for evaluating the effectiveness of TQM training and implementation practices.

8.3.3 Training

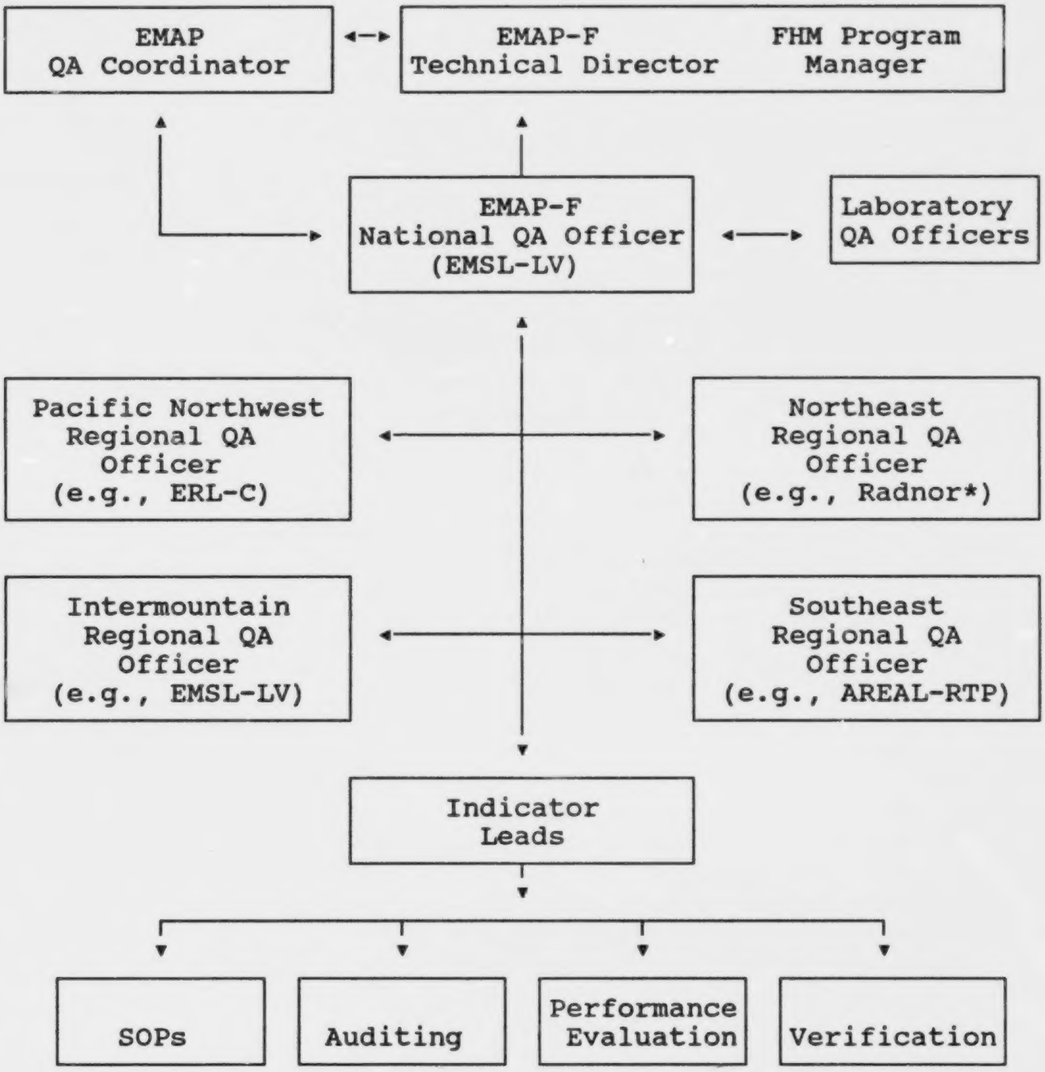
Training increases employee expertise and enhances employee decision-making capabilities. Given the complexity of EMAP, training should focus not only on technical proficiency, but also on the development of organizational and interpersonal skills.

A framework for TQM training and implementation at the agency level is the President's Award for Quality and Productivity Improvement. The award recognizes agencies that have implemented TQM in a manner that results in high quality products and services and effective use of taxpayer dollars. It also promotes quality and productivity awareness in all federal programs. A similar but more focused process within FHM could be developed for TQM recognition at the Resource Group, indicator, laboratory, field, or participant level. Methods for assessing the effectiveness of TQM at these levels in the FHM program have not yet been developed.

Tangible outputs from this focus on TQ could be in the form of an annual award, for example, with additional appropriate recognition in a newsletter format.

8.4 ORGANIZATIONAL STRUCTURE

Figure 8.3 represents the proposed organizational structure for the operations of the FHM QA Staff.


EMAP QA Coordinator
EMAP-F Technical Director
FHM Program Manager
EMAP-F National QA Officer (EMSL-LV)
Laboratory QA Officers
Pacific Northwest Regional QA Officer (e.g., ERL-C)
Northeast Regional QA Officer (e.g., Radnor*)
Intermountain Regional QA Officer (e.g., EMSL-LV)
Southeast Regional QA Officer (e.g., AREAL-RTP)
Indicator Leads
SOPs
Auditing
Performance Evaluation
Verification

*Headquarters for NE Forest Experiment Station.

Figure 8.3. Proposed organizational structure for FHM quality assurance staff.

8.4.1 Quality Assurance Coordinator

The quality assurance coordinator (QAC) has responsibility for the EMAP QA program and its implementation. The QAC serves as an advisor and interacts with the QA representative for each resource group (i.e., national QA officer for FHM) to ensure that each group projects the DQOs of the QAPP. The QAC also oversees the development of DQOs and documentation standards.

8.4.2 Technical Director

The FHM Technical Director (TD) coordinates several activities, including direct interaction with FHM participants, especially the National QA Officer and the indicator leads. Such QA functions include:

- Providing adequate resources.
- Coordinating development of DQOs.
- Overseeing development of QA project plans.
- Implementing TQM.
- Ensuring adequate training of personnel.
- Ensuring that audits are conducted.
- Supporting the QA program.

8.4.3 National Quality Assurance Officer

The national QA officer (NQAO) is responsible for QA in all FHM activities and reports directly to the FHM program manager and TD. Located at EMSL-LV, the NQAO will work closely with the indicator leads, regional QA officers, and other FHM participants, including the Forest Service (FS) on QA matters.

Specific responsibilities of the NQAO include:

- Providing input to the development of the EMAP QAPP.
- Developing of the FHM QAPjP.
- Guiding and overseeing activities of regional QA officers.
- Assisting in the development of the FHM information management system for data tracking, generation, and processing activities.
- Facilitating DQO development and methods selection within FHM.
- Developing guidance documents.
- Assisting the TD in implementing the QAPjP and QAMS documents and guidelines for the mandatory EPA QA program.
- Preparing the QA Annual Report and Work Plan, a document that summarizes the accomplishments of FHM and recommends improvements.
- Providing the laboratory communication link between the QAC, QA representative, and QAMS.
- Approving all contractual QA supporting documentation.
- Serving as a representative of FHM QA during EMAP resource group QA meetings.

8.4.4 Laboratory QA Officers

The laboratory QA officer (LQAO) is responsible for ensuring that each project within an EPA laboratory satisfies the laboratory's requirements for QA programs. The LQAO evaluates QA plans, coordinates and supervises systems audits, and disseminates information. The LQAO at EMSL-LV will work very closely with the NQAO to ensure that an appropriate QA program is developed. The issue of different EPA laboratory QA requirements will have to be addressed.

8.4.5 Regional QA Officers

A four-person core team of regional QA officers (RQAOs) will serve as a basis for the FHM QA structure. The NQAO will guide and oversee the QA activities of the regional QA coordinators. The RQAOs could be headquartered in close proximity to the center of regional FHM activities but not necessarily co-located there. Within the FHM QA group, the development of a QAPjP would include the cooperative efforts of the NQAO and RQAOs to ensure that the QAPjP guidelines were acceptable to all participants. For each region, the RQAO would be responsible for:

- Ensuring data quality following the guidance from the national QAPjP.
- Preparing a regional QAPjP.
- Selecting audit teams and conducting audits for the various in-house projects including follow-up audits.
- Preparing the QA Annual Report and Work Plan.
- Providing a communications link between the NQAO and regional personnel.

8.4.6 Indicator Leads

Each indicator lead within FHM has a QA responsibility for the data quality of each within-indicator measurement. To ensure that the resulting data are of acceptable quality, the indicator lead must be intimately familiar with components of the indicator such as sampling protocols, preparation, analysis, and logistics. Each indicator lead will be ultimately responsible for activities such as auditing, performance evaluation, and methods of verification (which includes accuracy and precision checks). The indicator lead will work closely with QA personnel in planning and conducting these activities. The RQAO will eventually be very active in actually conducting the audits. The indicator lead can develop protocols and provide training, but cannot physically audit 30 to 40 national field crews each year. However, for the FY91 sampling season, it is probable that the indicator leads will have to plan for their field audits. This could be done by training a non-crew field person. The NQAO and RQAO will serve as an advisor and resource person to the indicator lead. Cooperation between indicator leads and NQAOs is important in the development of each indicator.

8.4.7 Matrix Activities in EMAP

Data from other sources such as landscape characterization, air and deposition, and the other resource groups will be used. The FHM NQAO, working with the TD, will be responsible for coordinating QA activities with other cross-cutting groups and resource groups.

Liaison programs are designed to inform cooperating agencies and organizations. Several types of liaisons have been designated: intra-agency, congressional, and interagency. To date, the program directors (Associate Directors and above) have those liaison responsibilities.

8.4.8 Communications

The establishment of mechanisms and protocols for the exchange of information is essential to the success of any scientific endeavor. This is especially true for a program of such large scope and complexity as EMAP. EMAP QA communications must be timely and responsive.

Figure 8.3 can also be used to designate lines of communications. RQAOs will contact the NQAO to report progress or issues. The NQAO will be responsible for conveying information to TDs and the EMAP QAC. The RQAOs will be in communication with regional implementation/logistics personnel.

Conference calls will be established at regular intervals for the FHM QA staff to discuss QA issues. Conference calls between the NQAO and the EMAP QAC will also be established.

8.5 QUALITY ASSURANCE OBJECTIVES

8.5.1 Specific Objectives

Specific QA objectives that are being defined for FHM include:

- Compatibility of data – Common types of data generated by different methods and by different resource groups must be compatible. Data that describe the same measurement activity must also be compatible over time. Emphasis must be placed on data base flexibility because of issues, unknown now, which may arise in future years of this multi-year program.
- Satisfying the DQOs - Acceptance criteria established during the DQO-development process serve as benchmarks for satisfying data user requirements. The FHM DQOs may be established for several levels of data collection (e.g., sample measurement system, measurement parameter, or indicator level).
- Documentation of data collection -- Effective documentation will ensure that information on data quality, statistical design, algorithms, protocols, and analytical procedures are available for scrutiny. Documentation is also invaluable for any technical defense requirements. The scope and duration of EMAP will certainly require reexamination of data, methods, and conclusions as the program progresses. Thorough documentation is essential in establishing the flow of information, alternatives, decisions, and conclusions which form the basis for new activities or require the revision of previous conclusions based on new methods or information.
- Data verification – A systematic approach to data verification will ensure that all data are subjected to some basic standards of accuracy that verify the authenticity, but not necessarily the validity, of the data. Verification is accomplished by comparing data at each level of processing to established data quality criteria.
- Data validation – A systematic approach to data validation will confirm that environmental measurements, processes, and products are within acceptable bounds of accuracy and validity with respect to the population of interest.

8.5.2 Data Quality Objectives

The DQOs are considered to be specific statements of the level of uncertainty a data user is willing to accept in a body of environmental data, with respect to the kind of scientific or policy question that motivated the data collection activity. DQOs are definitive, quantitative, or qualitative statements developed by data users (e.g., scientists, policy makers, interest groups) in conjunction with the QA staff. The DQO process uses an iterative approach that balances costs versus uncertainty to achieve a desired or acceptable level of quality. This information can also be used to allocate or redirect resources to specific monitoring phases in order to generate data of sufficient quality to support management decisions or answer specific scientific questions. The FHM QA program could modify the QAMs process for establishing DQOs.

8.5.2.1 Hierarchy of DQOs

Data quality and DQOs can be defined for many levels of FHM data collection (Figure 8.4). Possible levels might include:

- Measurement-level DQOs (MQOs) for specific measurement parameters are estimated by using existing or initial baseline data. The MQOs may define acceptance criteria for detectability, precision, accuracy, representativeness, completeness, and comparability in field and laboratory measurement data (Byers et al. 1990). Another criterion may be to

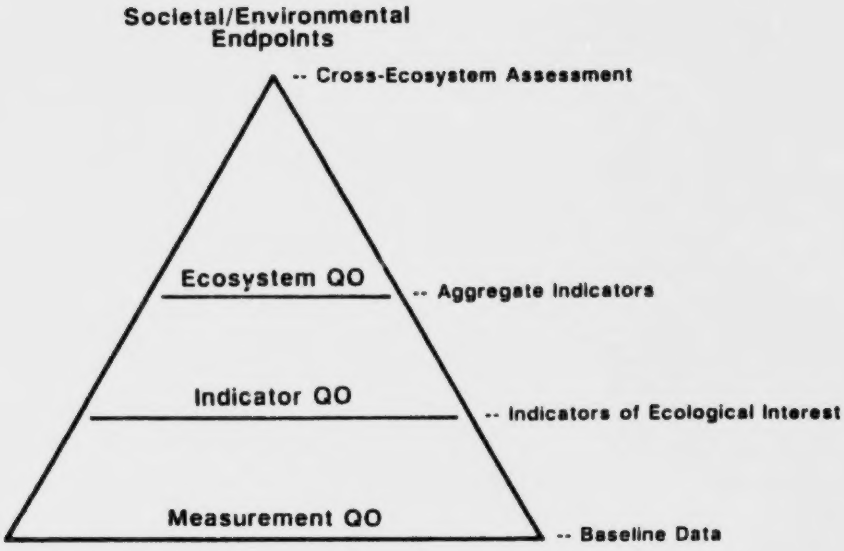

Societal/Environmental Endpoints
-- Cross-Ecosystem Assessment
Ecosystem QO
-- Aggregate Indicators
Indicator QO
-- Indicators of Ecological Interest
Measurement QO
-- Baseline Data

Figure 8.4. Hierarchy of data quality objectives.

optimize measurement uncertainty with respect to non-measurement sources of uncertainty (e.g., due to sampling design constraints or naturally-occurring spatial and temporal variability that often is confounded within environmental data).

- Indicator-level DQOs (IQOs) are derived from aggregated parameter data for ecological indicators. The IQOs might focus on the uncertainty associated with the data aggregation procedures that are used to assimilate measurement-level data. As the indicators are expected to provide specific information about resource condition, component factors such as measurement quality, sampling design, and statistical analysis will likely be important in developing these IQOs. The relative size of trends to be detected based on the specified indicators will provide important input in the development of the IQOs.
- Resource-level DQOs (RQOs) are derived from aggregated indicator data for the FHM Resource Group. At this level, indicator data may be aggregated to provide an overall FHM assessment of resource condition. Uncertainty associated with each indicator is an additional factor in the total uncertainty confounding the interpretation of resource condition.
- Ecosystem-level DQOs (EQOs) are derived from aggregated resource data for overall ecosystem assessments. Integrated data from all resource groups may be used by EMAP policy makers to make regional-scale assessments of overall ecological condition in different regions of the U.S. The uncertainty associated with each resource-level assessment must be included in the uncertainty estimate for the regional-scale assessment. This level of aggregation might not be feasible in the

FHM context. There might be many conflicting concerns/endpoints which EMAP managers do not want to try to aggregate.

8.5.2.2 The DQO-Setting Process

The development of DQOs will begin at the planning phase (i.e., research plan) and continue through intermediate phases (pilot studies and demonstration projects) and the implementation phase (regional monitoring and data interpretation). For FHM, the DQO process begins with the identification of environmental questions brought forward by EMAP directors, interest groups, and the public. These questions will focus overall monitoring objectives and help formalize and quantify appropriate DQOs in an interactive multi-staged process. Figure 8.5 highlights the interactions between "top-down" and "bottom-up" approaches in the development of DQOs.

Stage I defines major questions or issues of concern by focusing on the data user's information needs or requirements, resource and time constraints, and consequences of Type I and II errors. The Type I error (false positive) indicates the presence of adverse ecological effects when such effects actually do not exist. On the other hand, the Type II error (false negative) indicates the absence of adverse ecological effects when, in fact, real effects actually exist. Establishing the data user's information needs assumes that a consensus can be reached on these data needs from different data users. In reality, data quality will be assessed and documented during the early stages of the program. Reassessment and development of DQOs will be a continuous process.

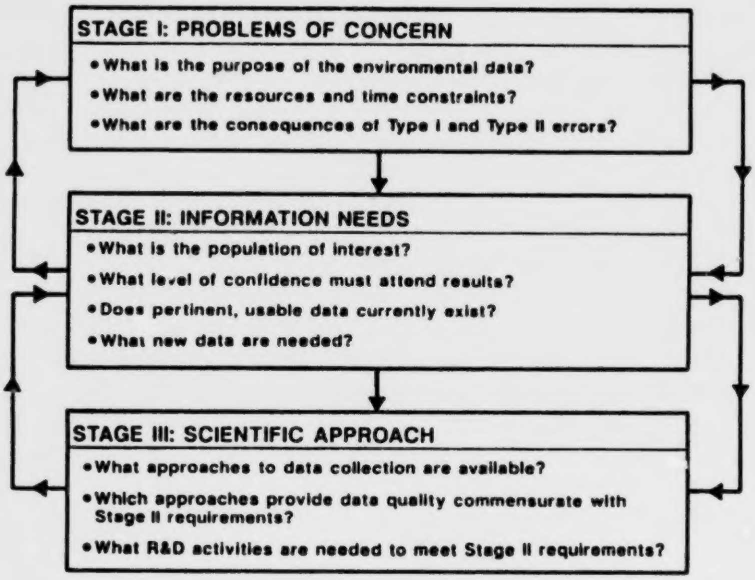

STAGE I: PROBLEMS OF CONCERN
• What is the purpose of the environmental data?
• What are the resources and time constraints?
• What are the consequences of Type I and Type II errors?
STAGE II: INFORMATION NEEDS
• What is the population of interest?
• What level of confidence must attend results?
• Does pertinent, usable data currently exist?
• What new data are needed?
STAGE III: SCIENTIFIC APPROACH
• What approaches to data collection are available?
• Which approaches provide data quality commensurate with Stage II requirements?
• What R&D activities are needed to meet Stage II requirements?

Figure 8.5. The DQO process for continuous communication and feedback among decision makers and scientists.

Stage II defines those data that are needed to answer the questions or make the decisions identified in Stage I. This exercise includes development of pertinent scientific questions, definition of the populations of interest, identification of specific design constraints, examination of existing data, and confirmation of requirements for collecting new data.

Stage III determines the scientific approach. Different approaches to data collection, critical levels of data quality required to meet Stage II constraints, and research needed to address Stage I and II concerns are identified.

A continuous chain of communication persists during the DQO-setting process and includes policy makers, program directors, resource scientists involved in data analysis, and scientists involved in the actual data collection activities (see Figure 8.6).

8.5.3 Current Status

The need for environmental information has been stated in very qualitative terms at Stage I. However, the EMAP steering committee has not yet indicated precisely how this information will be used by the various client groups that have been identified. Specific assessment criteria are being developed. These will define ecological condition, quantify its extent, and allow data users to articulate their data quality requirements in more quantitative terms than are presently available. For Stage II, a group of indicators must be developed that allow scientists to establish techniques for making overall assessments of resource condition. Rationale statements must be developed which describe the data to be collected for each indicator and the way in which those data will be used to provide information on ecosystem condition. Such statements might include critical values for condition and must

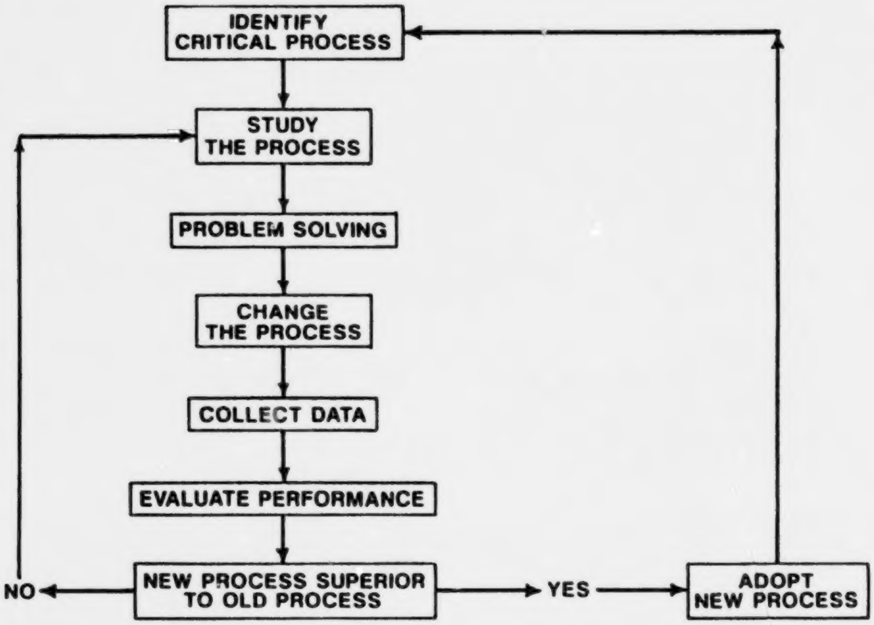


Figure 8.6. The DQO continuous improvement process.

be scientifically and statistically defensible. Rationale statements should also relate each indicator to assessment endpoints of societal interest so that the ramifications of changes in system condition can be understood and appreciated by the wide variety of data users.

In addition, a thorough investigation of data uncertainty sources must be conducted for each candidate indicator. If possible, actual estimates should be provided for each source of uncertainty. In this way, factors that contribute significantly to the overall variability of the indicator are identified and the effectiveness of various options in resource allocation can be evaluated.

Until appropriate aggregation techniques are developed, individual parameter or indicator assessments will be used to make discrete evaluations of condition. The techniques for making aggregated ecosystem-level assessments will be developed over time. The DQO process should provide the developmental framework by ensuring that assessment techniques at all levels provide information of sufficient quality to satisfy the FHM objectives.

At all levels, it must be the responsibility of the EMAP directors to initiate and encourage the development of DQOs. The EMAP QAC and a consulting group from QAMS have indicated an interest in facilitating this process. It is anticipated that the EMAP Steering Committee will be responsible for approving the IQOs developed for each resource group. Use of the DQO process will assure that the multi-level DQOs are consistent with the overall EMAP goals and objectives.

8.6 QA DOCUMENTATION AND REPORTING

8.6.1 Quality Assurance Project Plans (QAPjPs)

The EPA QA policy requires every monitoring and measurement project to have a written and approved QAPjP (Stanley and Verner 1983). This requirement applies to all environmental monitoring and measurement efforts authorized or supported by the EPA through regulations, grants, contracts, or other formal means.

8.6.1.1 Purpose of the QAPjP

The QAPjP for FHM will specify the policies, organization, objectives, and functional activities for the specific project. Each plan will also describe the QA activities and assessment criteria that will be implemented to ensure that the data bases will meet or exceed all DQOs established for FHM. The QAPjPs will be revised as necessary to reflect changes in procedures that result from continuous improvement. All project personnel, especially indicator leads, should be familiar with the policies and objectives outlined in pertinent sections of the QAPjP to ensure proper interactions among the various data acquisition and management components.

Due to the evolving nature of the research plan, topics covered in the QAPjP are generic in nature. As modifications to the research plan are made, these descriptions will be revised to address any modification.

8.6.1.2 Content of a QAPjP

The QAPjP must identify all environmental measurements within the scope of the project goals and objectives and identify specific processes within each measurement that could introduce possible sources of error or uncertainty in the resulting data. Methods, materials, and schedules for assessing the error contributed by each process must also be addressed. The QAPjP must also define the criteria and procedures for assessing statistical control for each measurement parameter.

Data collection activities must institute sufficient control procedures, materials, and techniques to minimize measurement errors. Each process that could affect the quality of the data (e.g., sample collection, preservation, transportation, storage, preparation, analysis, and data reporting) must be evaluated and documented.

There are several QA requirements in the QAPjP to monitor the step-wise process for environmental measurements (Figure 8.7). By using appropriate measurement quality samples, it is possible to isolate the error contribution and set control criteria based upon the overall MQOs. This approach is essential for providing diagnostic information so that real time corrective action can be taken to ensure control in satisfying these DQOs.

Although the information in Figure 8.7 represents traditional data collection activities, these guidelines might not be feasible for identifying every error-contributing process given technical and resource constraints. It is essential that the QAPjP define the rationale behind each QA application, describe the specific measurements, and highlight the application of QA in each case.

The QAPjP must also identify FHM services that will be used to support QA and assess the effectiveness of the QA program. These include the QA responsibilities of individuals in the project, preventative maintenance of instrumentation, and scheduling and scope of the audit program.

8.6.1.3 Responsibility

The TD for each EMAP resource group delegates responsibility for generating the QAPjP to the resource group QAO. Through the QAPjP, program directors will establish policies, criteria, and procedures related to QA. Specific sign-off authority by program directors has been established to assure concurrence with the scope and content of the QAPjP elements.

8.6.2 Standard Operating Procedures

Environmental monitoring SOPs are devised for sampling, preparation, and analysis, data management, QA, reporting activities, accounting, project finance and contracts, and analysis integration activities.

Written SOPs provide guidelines for planning, implementation, and analysis activities over time and among personnel for routine activities within an organizational unit (e.g., resource group), but not among units. To ensure consistency in data among resource groups, SOPs must be cooperatively developed. In field and laboratory circles, SOPs are often referred to as "methods" or "protocols." The incorporation of QA into methods development is very important. The QA personnel should have an active cooperating role in methods development with each indicator lead. Subsequently, an active sample exchange program will be initiated when multiple laboratories are contracted for analyses. Comparability of data from various

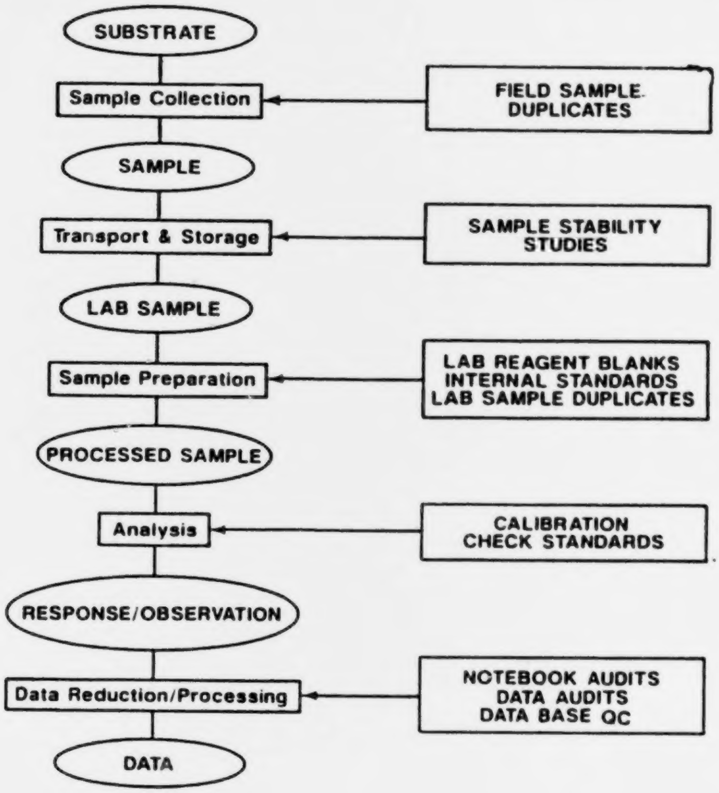

SUBSTRATE
Sample Collection
FIELD SAMPLE DUPLICATES
SAMPLE
Transport & Storage
SAMPLE STABILITY STUDIES
LAB SAMPLE
Sample Preparation
LAB REAGENT BLANKS
INTERNAL STANDARDS
LAB SAMPLE DUPLICATES
PROCESSED SAMPLE
Analysis
CALIBRATION CHECK STANDARDS
RESPONSE/OBSERVATION
Data Reduction/Processing
NOTEBOOK AUDITS
DATA AUDITS
DATA BASE QC
DATA

Figure 8.7. Assessment and control of process errors within a measurement.

field and laboratory sources is a QA issue of considerable importance.

The TD for FHM is responsible for determining which activities require SOPs and oversees the development, review, and implementation of these SOPs. During periodic audits, the NQAO for FHM should document the status of all new SOPs.

8.6.3 Documentation

Current versions of the following documents and information must be disseminated among all appropriate FHM participants and cooperating organizations:

- QAPjP - A document addressing all items delineated by Stanley and Verner (1983). These include clearly defined field and laboratory protocols, including QA staff responsibilities, and use of QA protocols, and project DQOs.
- Laboratory methods manual - A document containing detailed SOPs related to laboratory and instrument operations.
- Field methods manuals - Documents containing detailed instructions, including field forms, for all field operations.

8.6.4 Reports to Management

- Monthly Reports - The NQAO will submit monthly reports to the TD and the QAC. The report will discuss QA issues,corrective actions, and accomplishments. The QAC will submit a monthly report to the EMAP Terrestrial Systems Associate Director. This report will summarize the overall FHM QA activities. Delivery dates have been specified as the 5th of the following month for the QAO report and the 10th for the QAC report.
- Audit Reports - Management systems reviews (MSRs) and technical systems audits (TSAs) are stand-alone reports to be delivered through specified channels on an on-going basis. Audits of data quality (ADQs) and performance evaluation audits (PEAs) are incorporated into the monthly reports. The QAO is responsible for reporting the TSA, ADQ, and PEA reports.
- QA Annual Report and Workplan - The FHM QA Annual Report and Workplan (QAARW) discusses project activities during the prior fiscal year. Recommendations for changes in QA policy (with appropriate justifications) are also addressed. The workplan component of the QAARW describes all major QA activities for the coming year, including DQO developments and refinements, deliverables, audit schedules, changes in the QA program, resource requirements, active projects, tasks involved in data generation, and approved changes in the QAPjPs and SOPs. The annual report of the QAC will be appended to the QAARWs for each resource group.

8.7 QA OPERATIONS

The following subsections describe the methods used to control and evaluate the quality of data produced during the data collection process (see Figure 8.8).

8.7.1 The Audit Program

The FHM QA staff will develop and conduct laboratory and field audits and reviews at the program and project levels. These audits, which will be conducted with the cooperation of the FHM indicator leads, will aid in determining whether the QAPjPs are being fully implemented, and if they are adequate for the objectives of the project. Audits will be conducted for all data collection measurements.

8.7.1.1 Categories of Audits

QAMS has classified audits into four categories (EPA, 1987) as follows:

- Management Systems Reviews (MSRs) - assess the effectiveness of the implementation of the EMAP QAPP.
- Audits of Data Quality (ADQs) - used to check data accuracy, to determine whether or not sufficient information exists within the data set to support assessment of data quality, and to verify that DQOs have been satisfied.
- Technical Systems Audits (TSAs) - an on-site visit used to verify conformance to the QAPjPs and to confirm that good laboratory and field practices have been used in the generation of the environmental data.
- Performance Evaluation Audits (PEAs) - assess laboratory and field analyses based on results achieved in the analysis of blind samples; also serve as a check on the comparability of data between resource groups. Indicator leads will be active participants with QA personnel in developing and conducting these PEAs. The possibility of field reference plots for auditing the performance of field crews is being considered.

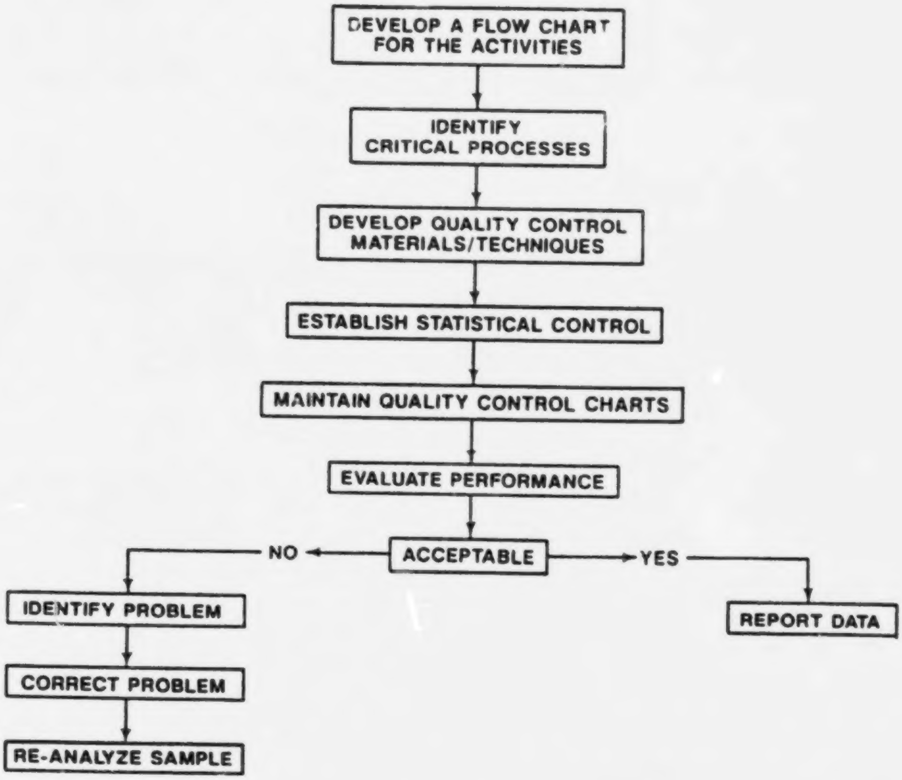

DEVELOP A FLOW CHART FOR THE ACTIVITIES
IDENTIFY CRITICAL PROCESSES
DEVELOP QUALITY CONTROL MATERIALS/TECHNIQUES
ESTABLISH STATISTICAL CONTROL
MAINTAIN QUALITY CONTROL CHARTS
EVALUATE PERFORMANCE
ACCEPTABLE
NO
YES
IDENTIFY PROBLEM
CORRECT PROBLEM
RE-ANALYZE SAMPLE
REPORT DATA

Figure 8.8. Data collection process.

8.7.1.2 Corrective Action

The TD has the responsibility for verifying corrective action for discrepancies documented in the audit report. The NQAO is responsible for tracking the corrective actions. A Memorandum of Intent (MOI) must have a concurrence page for sign-off. The MOI identifies the problems and/or discrepancies, the corrective action(s), and the remedial effects.

8.7.2 Data Verification

Verification is the act of determining and controlling the quality of data. Verification can be accomplished manually, electronically, or through remeasurements.

8.7.2.1 Electronic Data Verification

All FHM data will eventually be placed in an electronic format. Much of the data collected in 1990 was entered into portable data recorders in the field. Computer programs can be designed to perform logic checks of most entries, automatically determining if the code entered is valid and logically correct.

Data can also be verified by relating it to other correlated measurements (e.g., height to diameter, and pH in different extracts). If data verification is accomplished during or immediately following data collection, outliers may be identified and spurious data may be corrected.

Many basic data verification programs have been developed for the field portable data recorders. Extensive verification programs similar to those used in the DDRP surveys (Papp et al. 1989) were developed for soil samples collected during the 20/20 pilot study.

8.7.2.2 Remeasurements

Remeasurements of field parameters are another method of data verification and are a technique for verifying relatively subjective field observations such as percent defoliation. Remeasurements can be accomplished by the following methods:

- Field crews remeasuring a statistically valid percentage of their own plots to estimate within-field crew precision.
- Field crews measuring reference plots. The data allow a measure of accuracy and between-crew precision.
- Remeasurements by a check crew visiting plots previously measured by other crews. This is another method of estimating crew precision.

In 1990, each field crew remeasured at least one of their own plots and a check crew remeasured a small percentage of plots. The QA staff will attempt to establish reference plots in the coming years. Issues such as confidentiality and multiple visits will be considered.

9 LOGISTICS APPROACH

9.1 INTRODUCTION

Implementing a national Forest Health Monitoring (FHM) Program will require detailed, comprehensive logistics planning. A logistics plan will be developed prior to implementing any operational phases. The plan will assist in the five operational phases:

1) Field sampling,
2) Sample and data handling/shipping,
3) Sample preparation,
4) Sample analysis, and
5) Sample archive.

The FHM Logistics Plan serves two purposes: 1) to provide information on the concept of FHM and detail the responsibilities for logistics, and 2) to serve as a guide to the development of regional logistics plans. The active tense used in this section indicates the author's opinion about how logistics could be accomplished in FHM. The concepts within this section must be reviewed and approved through the FHM multi-agency process.

9.1.1 Current Status of Logistics

In October 1989, the USDA Forest Service (FS) and the EMAP-Forests team started discussing plans for a multi-agency monitoring program and established national technical committees (see Section 9.3). The Logistics National Technical committee met at Research Triangle Park, North Carolina, in January 1990 to develop the Joint National Monitoring Plan. The operational phases were identified at this meeting and in the following months, and the logistics plan was developed and distributed for internal review. The document is still being developed.

At the time of the January meeting, it was known that FHM would be implemented by the FS in the six New England states. The logistics aspects of this field activity would be the responsibility of the FS. Much of this activity was turned over to state forestry personnel. During the summer of 1990, a pilot study was conducted to test indicators on 20 sites in New England and 20 sites in Virginia. The EMAP-Forests logistics team assumed primary responsibility for this activity.

In 1991, the FS plans to implement FHM in the New England States, New Jersey, Delaware, Maryland, Virginia, Georgia, and Alabama. The FS will be responsible for logistics. The EMAP-Forests team plans on additional field work for indicators that are not fully implementable in the states mentioned above and will be responsible for the logistics of this activity.

9.2 LOGISTICS ISSUES

9.2.1 National Planning

The Logistics National Technical Committee, which is developing a draft of the National Logistics Plan, has not been appropriately represented both spatially (FS regions) or organizationally (Forest Pest Management, National Forest System) to capture all the logistics issues. The National Logistics Plan should be a guidance document for implementation within the four proposed mega-regions (see Figure 11.3). The document should represent the minimum requirements needed to satisfy the national program. Therefore, efforts will be made to develop this document in FY91 and gain acceptance of the document over all mega-regions.

9.2.2 Agency Responsibility

The success of FHM is dependent on interagency cooperation with the FS (all branches) and with other agencies that will participate in the program such as the Soil Conservation Service (SCS), National Park Service (NPS), Bureau of Land Management

(BLM), U.S Fish and Wildlife Service (FWS), etc. The roles of the various agencies must be established and responsibilities must be defined.

Currently, the FS and the EPA have been implementing all phases of logistics, the FS during implementation and the EPA during pilot testing and demonstrations. However, each agency brings unique expertise to the program. In 1991 the National Technical Committee will review the logistics implementation phases and decide which agency could best implement specific phases.

9.2.3 Design and Indicators

A number of design and indicator issues must be resolved before a definitive logistics plan can be developed and implemented.

As stated in the field scenario (Section 9.4.1), the FS and the EPA have agreed to sample all forested (~5000) Tier 1 sites. However, it has not been resolved whether all sites or a subset of these sites will be visited each year. In addition, a decision must be made on whether to measure indicators together (full-suite) on a plot or in different years.

These issues have a significant impact on the logistics of the program, particularly staffing, reconnaissance, and procurement activities. The design and indicator technical committees will address these issues in 1991.

9.2.4 Resource Integration

Logistics efforts among EMAP resource groups should be coordinated and integrated as much as possible to defray program costs. Shared, regional logistics centers with permanent warehouse facilities will aid in this integration. The Boise Interagency Fire Center (BIFC) may serve as a model for the future regional logistics centers. A national logistical support center, the BIFC is an interagency program with agreements between the BLM, U.S. Bureau of Indian Affairs, FS, NPS, National Weather Service, and FWS. The BLM manages the land and facilities and is host to the other five agencies. Similar arrangements need to be considered for interagency EMAP logistics centers.

9.3 ORGANIZATIONAL STRUCTURE

Figure 9.1 is an example of the organizational structure of logistics. This organizational structure is dependent on FS and EPA agreement at the Washington, station, and work-unit level.

9.3.1 National Steering Committee

The National Steering Committee is comprised of FS personnel from Forest Inventory and Assessment (FIA), Forest Pest Management (FPM), FS management, FS state personnel, and EPA management. The National Steering Committee, with assistance from the National Technical Committee, develops policy for the national program.

9.3.2 National Logistics Technical Committees

The National Logistics Technical committee consists of state, FS, and EPA personnel. The technical committee develops logistics protocols for the national program in a manner that will provide consistent and comparable information across the sampling regions of the United States. The technical committee is responsible for planning and scheduling all phases of FHM data collection.

The EPA has identified two individuals to assist on the National Logistics Technical Committee. These two individuals will oversee EPA regional logistics leads. Due to different

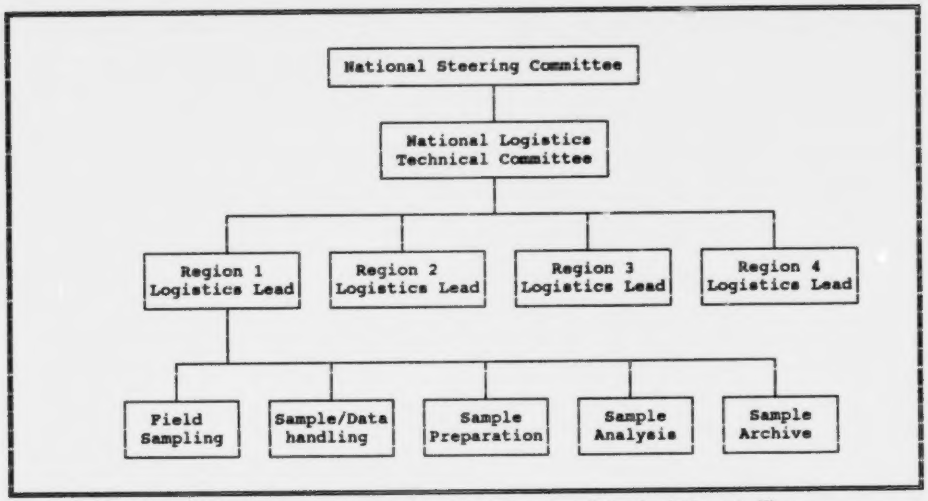

National Steering Committee
National Logistics Technical Committee
Region 1 Logistics Lead
Region 2 Logistics Lead
Region 3 Logistics Lead
Region 4 Logistics Lead
Field Sampling
Sample/Data handling
Sample Preparation
Sample Analysis
Sample Archive

Figure 9.1. Partial example of a flow chart for describing logistics staffing.

organizational structures, the FS may need to represent national interests with more personnel. Workshops will be held fre-quently until the National Logistics Plan is completed. After the plan is completed, semi-annual meetings could be held to discuss issues pertaining to implementation of sub-sequent surveys and to wrap up current year activities.

The technical committee, with guidance from the National Steering Committee, will define the logistical responsibilities of each agency. At the national level, the roles will be distributed within the two primary agencies (EPA/FS). Each agency will determine the means to accomplish its responsibility (i.e., state assistance or subcontracting), then forward their decision to the executive committee for final approval.

9.3.3 Regional Logistics Leads

At a regional level, an organized logistics team will be given responsibility for certain elements of logistics. The regional logistics leads will manage all logistics phases of the program within the guidelines of the National Logistics Plan.

The difficulty of coordinating the logistics activities of 30 to 40 field crews across the nation necessitates the creation of regional logistics centers. These centers, which could be established at regional technical centers, could house regional program leaders.

9.4 LOGISTICS IMPLEMENTATION COMPONENTS

Table 9.1 identifies a number of logistics issues within the five operational phases (see Section 9.1). Responsibilities for each of these components will be determined by project managers and logistics leads. These elements will be addressed fully in each of the regional logistics plans prior to implementation of field activities. This can only be accomplished through long-range planning and coordination. Each element is not necessarily the responsibility of logistics; however, the logistics plan identifies who is responsible for completing the activity and

Table 9.1 EMAP logistics elements for implementation of forests monitoring programs.

1. Planning
2. Review of Logistical Activities
3. Staffing
4. Procurement & Inventory
5. Reconnaissance
6. Training
7. Communications
8. Contracting
9. Safety
10. Scheduling
11. QA/QC
12. Information Management
13. Review/Recommendations
14. Inventory/storage

who provides a status summary. A timeline or Gantt chart (see Figure 9.2) will delineate all milestones or critical path activities. Timing for most logistics activities is dependent upon completion of prior logistics operations. Therefore, the chart will be updated continually as the schedule changes or as activities are completed. Revisions will be dated. Sections 9.4.1 - 9.4.14 discuss each of the logistics elements that are listed in Table 9.1.

9.4.1 Field Operations Scenario for FHM

The following field operations scenario is presented to demonstrate that the proposed field activities are logistically feasible within the allotted timeframe. This scenario represents only one of many that could be developed at this time. All FHM personnel have not agreed on all the assumptions of this scenario. The scenario is based on field implementation and pilot tests that were implemented in 1990 and eight assumptions:

1. Implementation started in 1990 with 263 sites in six New England states. A pilot study was conducted in New England and Virginia. Additional regions and pilot studies will be phased into the program in subsequent years. The program will be fully implemented across the nation by 1995.

2. All Tier 1 sites (~5,000) will be sampled for Tier 2 sampling. It is estimated that one quarter (1,250) of these sites will be sampled each year; a complete sampling cycle will take four years.

3. The distance between sites at the Tier 1 density will be approximately 30 miles. Travel between plots is estimated at 2 to 3 hours.

4. Site selection does not consider access.

5. Five indicators of forest health will be sampled at each sampling site (see Section 3). As new indicators are added or the additional list is modified, the elements within the logistics plan must change.

6. Data collection activities at a site are limited to one day. Including field crew travel between plots, it is estimated that a crew could complete three plots in a week.

7. A field crew of five people will be required to sample a site in a day.

8. Sampling will take place in an index period that may vary for different sampling regions. Generally, the index period will last from June through August.

Based on these assumptions, 30 to 40 field crews will be necessary to complete the national sampling program. Allowance for downtime due to weather and other factors will have to be considered in determining the actual number of field crews. To organize and coordinate the activities of the field crews, four regional logistics centers (1 per mega-region) will be established.

Under these assumptions, it is the responsibility of logistics to provide the most cost and time efficient method to collect data while maintaining data quality. Changes in any of the assumptions could change the logistics plan.

9.4.2 Planning

Planning is essential to any program as large and complex as the FHM program. At a national level, it will be critical that the phases of logistics that are occurring in each region be tracked and that the phases are implemented within critical timeframes. The national logistics team must also coordinate with other technical groups to assure that decisions affecting logistics occur within appropriate timeframes. The following Gantt chart (Figure 9.2) is an example of a timeline the national logistics team would maintain. Because the program is in its inception, the national logistics team and the regional logistics leaders should be identified; they should meet on a regular basis (possibly every 3 months) to develop the National Logistics Plan and the regional logistics plans. After the plans are developed, planning meetings could occur twice a year.

9.4.3 Staffing

Staffing and personnel requirements encompass logistics personnel, field crews, preparation laboratory personnel, office personnel, training crews, and QA crews. In this section, the qualifications of each position will be addressed in terms of hiring. Timelines will be developed, identifying when resumes will be reviewed, when interviews will be conducted, and when positions will be filled. The organization through which each position will be hired (FS, EPA, cooperators, or contractors) will be determined. Determining how key personnel will be kept on staff during slack periods of the program will also be discussed.

9.4.3.1 Logistics Personnel

Logistics personnel will provide support in the following areas:

- Equipment and consumable procurement, storage, maintenance, and repair.
- Vehicle procurement, maintenance, and repair.
- Sample storage, tracking, packing, and transfer.
- Lodging, timekeeping, etc.

The primary objective of field logistics is to keep the samplers sampling. Field logistics will attempt to accomplish any tasks that would deter a crew from sampling.

Logistics personnel must be familiar with the objectives of the program and the requirements of each indicator. Each element listed in Table 9.1 must be addressed by the logistics personnel. The position requires an eye for detail and experience in acquiring goods and services.

After data and sample collection and transfer, logistics personnel will be responsible for the following activities:

- Staffing of preparation or analytical laboratories.
- Training of preparation or analytical laboratory staff.
- Scheduling.
- Contracting.
- Data Handling.
- Procurement and inventory.
- Sample storage, tracking, packing, and transfer.

9.4.3.2 Field Personnel

The following issues need to be addressed to adequately staff field crews within a region:

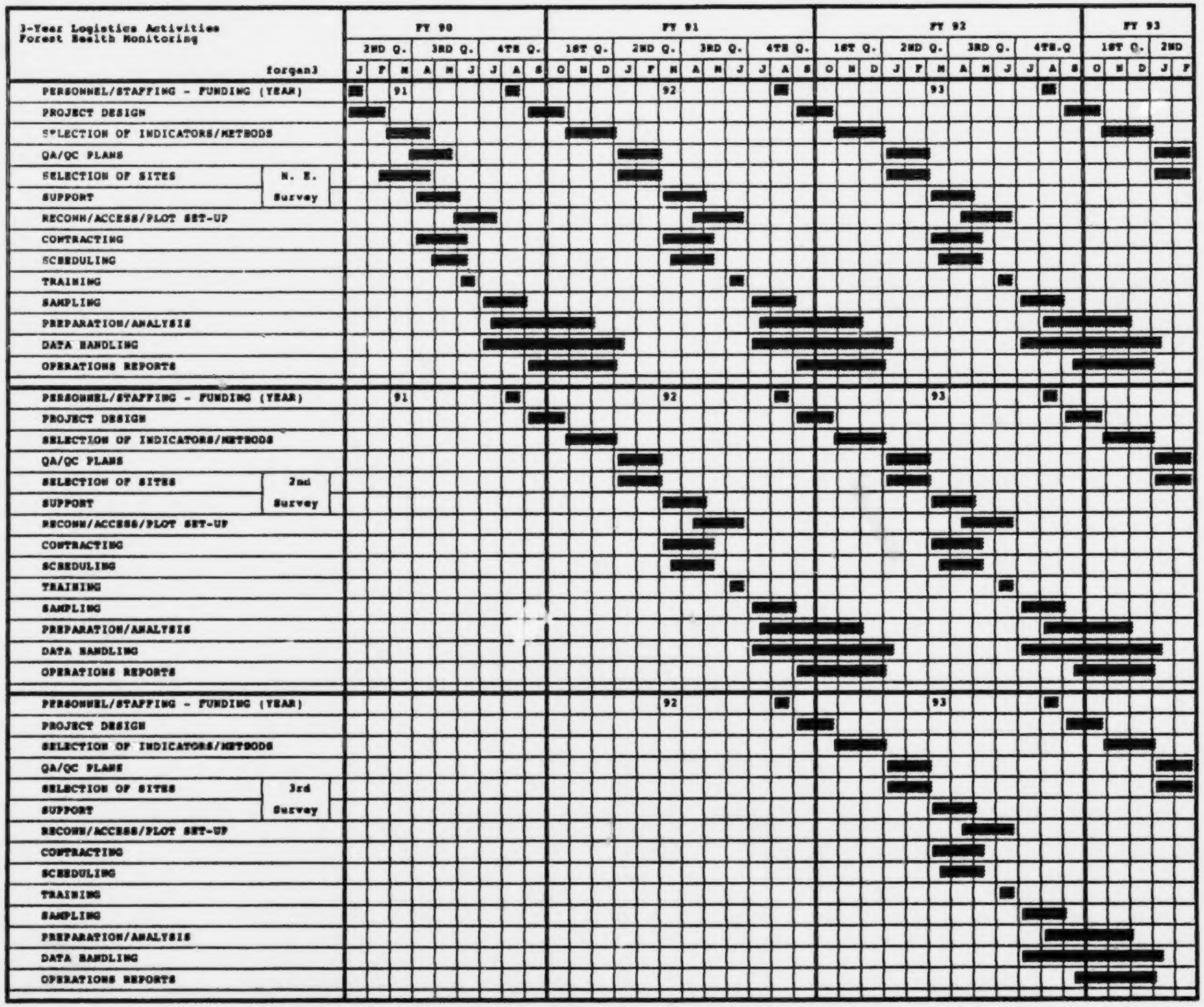


Figure 9.2. FHM/EMAP 3-Year Gantt chart of activities.

- Identification of the organization responsible for staffing the various activities.
- Determination of the total number of plots.
- Locations of the plots.
- Identification of the measurements to be made on each plot.
- The levels of education, experience, and training required for field personnel.
- The standard operating procedures for each measure and the time required to carry out each procedure.
- The retention of key personnel.
- Work schedules (overtime, etc.)
- Contingency plans for replacing staff members, either temporarily or permanently.
- Acquisition of expertise outside EPA/FS (SCS/universities/consultants)

Figure 9.3 depicts the organizational structure of the field staff.

Project Manager

The project manager is the national lead for the field monitoring phase of the program. This title could be held by a single individual or by a committee. The project manager ensures that field monitoring is accomplished in all regions and information is properly disseminated.

Regional Project Leader

The regional project leader oversees field monitoring activities in a particular region. This individual disseminates information (progress/problems) upward to the project manager and downward to the field crew. This person maintains adequate staff to assist in different elements of this task (i.e., data management, logistics, reconnaissance).

Field Crew Leader

The field crew will be supervised by a designated crew leader who is a member of the crew. The crew leader will supervise all field operations and resolve discrepancies or issues as needed at the site. The field crew leader is responsible for:

- Maintaining and revising sampling schedules and itineraries.
- Assigning duties according to sampling priorities.
- Ensuring that all sampling protocols are followed.
- Ensuring proper use and maintenance of field equipment.
- Maintaining the integrity of the site and samples collected.
- Reporting problems or difficulties to proper management staff.
- Returning all field equipment and supplies.
- Maintaining communications activities.

Field Crew

The information obtained from the pilot study conducted in 1990 (Figure 9.4) indicates that a five-person crew is needed to sample a site for the five indicator measurements presently proposed for sampling. The five-person field crew will be comprised of:

- 2 Foresters (visual symptoms, growth) with work-related experience in mensurational-type measurements.
- 1 Soil scientist (soil sampling) who is familiar with National Soil Survey characterization and sampling methods.
- 2 Forest technicians (foliar sampling, vertical vegetation, growth) who are experienced in tree climbing and foliar sampling techniques.

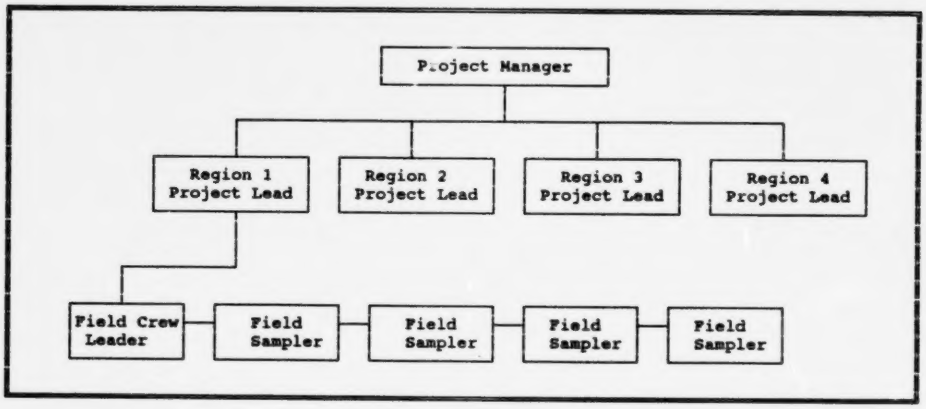

Project Manager
Region 1 Project Lead
Region 2 Project Lead
Region 3 Project Lead
Region 4 Project Lead
Field Crew Leader
Field Sampler
Field Sampler
Field Sampler
Field Sampler

Figure 9.3. Partial example of a flow chart for describing field staffing.

Indicator	# People	Hours	Tot. hrs
Soil Sampling	1	8	8
Foliar Sampling	1	3	3
Vertical Vegetation	2	2.5	5
Growth	2	2	4
Visual Symptoms	2	5	10
			30

Figure 9.4. Estimated time requirements for indicator implementation.

As new indicators are developed and others are replaced, staffing requirements will be reevaluated.

To accommodate field personnel from different organizations, a work schedule for the crew will be developed. Ten-hour work days are needed. Within the FS and EPA, there are a number of work schedules that can be adapted (e.g., four ten-hour days, eight days on four days off, etc.). The most efficient schedule will take data quality, crew efficiency, and program expenditures into consideration.

9.4.3.3 Preparation Laboratory Personnel

Logistics personnel will recruit personnel and acquire facilities for the preparation of soil and foliar samples. The following issues need to be addressed:

- Identification of the organization responsible for staffing the various activities.
- Determination of the total number of samples each year.
- The levels of education, experience, and training required for laboratory personnel.

- The standard operating procedures for each measurement and the time required to carry out each procedure.
- The retention of key personnel.
- Work schedules (overtime, etc.).
- Contingency plans for replacing staff members either temporarily or permanently.
- Acquisition of expertise outside EPA/FS (SCS/universities/consultants).

The work schedules of the preparation laboratory staff will conform to the field sampling schedule; therefore, the preparation facility could be operational six days a week.

Preparation Laboratory Manager

The preparation laboratory manager is responsible for maintaining the integrity of all samples upon their arrival at the laboratory facility. The laboratory manager must be knowledgeable in laboratory methods and procedures and have demonstrated ability to track large numbers of samples and supervise laboratory personnel.

Ultimately, the laboratory manager is responsible for assigning duties according to the specific project needs. The following division of responsibilities is tentative and may be adjusted.

- Coordinates laboratory operations and time management.
- Communicates with QA manager and QA representative.
- Communicates with sampling task leaders and indicator leads.
- Oversees sample receipt and storage.
- Oversees all computer data entry and evaluation procedures.
- Oversees sample preparation and analysis activities.
- Organizes analytical samples into batches.
- Tracks all samples during processing.
- Assists other analysts after other duties are complete.

Sample Preparation Staff

After the program is fully implemented, adequate staffing will be provided to ensure a fast and efficient turnaround of samples from the field to the analytical laboratories. All personnel must be thoroughly trained in the protocols and safety procedures by the laboratory manager before sample processing begins.

The preparation laboratory staff will complete the following activities:

- Sample receipt/tracking.
- Sample storage.
- Sample drying.
- Sample analysis.
- Sample disaggregation/sieving.
- Sample homogenization and subsampling.
- Sample batching.
- Sample archiving.
- Data entry, verification, and reporting.

9.4.3.4 Office Personnel

The regional and national programs will need office personnel for word processing, travel assistance, timecards, etc. Personnel requirements, responsibilities, and funding estimates will be identified.

9.4.3.5 Training Personnel

Before each field season, field crews and preparation laboratory personnel will be trained in the sampling, data collection, and analysis methods. Experienced instructors will be recruited. Logistics personnel may be responsible for obtaining these individuals for training. Training will include:

- Sampling/preparation methods.
- Quality assurance.
- Safety.
- Information management (data entry/verification).

- Sample shipping/handling.
- Logistics (equipment procurement, maintenance, time keeping, etc.).

9.4.3.6 Quality Assurance Crew

QA crews will be visiting a prescribed number of sites within each region. The regional logistics leads will brief the QA crew on site location, crew sampling schedules and site completions, lodging accommodations, and equipment/vehicle procurement.

9.4.4 Procurement and Inventory Control

The success of any survey depends on appropriate equipment, supplies, and services being supplied on time and at adequate levels. The appropriate methods for enumerating supplies and functional equipment on hand, assessing future needs, and ordering and restocking replacement supplies and equipment on a timely basis will be addressed. The specific equipment and support needed to satisfy each of the categories listed in Table 9.2 and the process by which equipment will be procured will be determined. Close coordination with design and indicator teams to identify the equipment, supply, and service requirements is essential. Procurement schedules will be tracked very closely and included in Gantt charts.

9.4.5 Reconnaissance

Reconnaissance of base sites and sampling sites can reduce the time and effort of field sampling.

9.4.5.1 Base Site Reconnaissance

Base sites may be necessary to assist sampling personnel by supplying consumable supplies, acquiring equipment, shipping samples, and assisting field crews whenever necessary.

Selection of base sites will be founded upon the proximity of sampling sites to towns or cities; the capabilities of towns or cities to

Table 9.2. List of supply needs for logistics.

1. SCIENTIFIC INSTRUMENTATION
    a. measurement devices
    b. recording devices/data forms/log books
    c. power sources
    d. calibration gear
    e. maintenance/repair gear

2. SAMPLING EQUIPMENT
    a. containers
    b. labels and markers
    c. data forms/log books
    d. collection devices
    e. preservatives
    f. shipping containers and accessories

3. SAFETY EQUIPMENT
    a. clothing
    b. communication
    c. flotation
    d. first aid

4. TRANSPORTATION
    a. vehicles
    b. canoes
    c. maintenance gear

5. COMMUNICATION
    a. radio
    b. telephone
    c. computer
    d. facsimile

6. ADMINISTRATION
    a. photocopier
    b. forms (e.g., time cards)

support base sites will also be a deciding factor (see Table 9.3). These base sites may be fixed or mobile, depending on logistical requirements. Geographical information systems (GIS) can provide digital line graph (DLG) maps overlaid with locations of support services. The list of potential base sites can be narrowed by using reconnaissance activities.

Base site operations require specific utilities. Telephone lines will probably be essential for satisfying the communications plan. If telephones are unavailable at remote locations, alternate methods such as radio communication will be considered. There must be access to the appropriate fuels for access vehicles.

There must be adequate space for calibrating field instruments and preparing samples. Separate storage space is necessary for equipment, reagents, samples, and wastes. This may require climate controlled environments such as refrigerators or freezers. Security of storage areas will be addressed in the base site plan.

If chemical or biological wastes are generated, the base site must be located either within the range of a qualified shipper or have local facilities available to handle these wastes.

Shipping facilities are necessary for movement of samples, supplies, and mail. Pickup and delivery service will match the daily and weekly schedule dictated by the sampling methodology. If the maximum holding time for samples is minimal, then overnight service will be available.

Local service and supply stores such as hardware stores, sporting goods stores, and auto service centers will be considered in the selection of base sites. There should also be personnel support services in the vicinity. These include lodging, food, banking, and mail services. If the same base site is used for more than several weeks, hotel accommodations may become expensive and confining. Leased homes can provide a good alternative.

9.4.5.2 Sampling Site Reconnaissance

The site access plan will address how reconnaissance information about a site will be collected and how written access permission will be obtained. It will describe how and when appropriate government agencies will be contacted to obtain permits

Table 9.3. Base site technical support requirements.

I. PROXIMITY TO SAMPLING SITES

II. UTILITIES

  A. Phone
  B. Fuel
  C. Electric
  D. Water

III. SPACE
  A. Sample preparation/analysis
  B. Storage
    1. equipment/reagents
    2. samples
    3. wastes

IV. WASTE DISPOSAL FACILITIES

V. SHIPPING FACILITIES

  A. Samples
    1. pickup and delivery
    2. overnight shipment
    (if methods require)
    3. high volume carrier

and site information. Important site data needed from these agencies include land ownership information and physical access information. Other information in the access plan includes locations of the nearest emergency services and the types of physical or biological hazards near the sampling site. A person will be identified to gather this information and to disseminate it to the personnel who will visit the site. Figure 9.5 is a flowchart of an access plan.

All sites should be visited before field sampling. If possible, access into the plots will be marked for field crews. If this is impossible, detailed sketch maps will be drawn and obvious starting points will be identified. Global positioning systems will be tested to develop this capability. Sampling sites identified as having potentially difficult physical or legal access will be identified. If the access problem is physical, additional resources (e.g., addition of a crew member or alternative access vehicle) required to obtain samples from the site will be identified. Field crews will be notified of such cases and allocated additional time and resources for sampling these sites. If access is legally denied, the sites will be reported to the design team. The design team will determine if the site will be dropped or if an alternative site will be selected. Field crews will be given a copy of each site dossier pertaining to their sampling sites in order to contact landowners prior to visits and to access the sites appropriately.

9.4.6 Training

Training is essential to the success of data collection activities. Training enables personnel to complete each aspect of operations according to design and management objectives and in a standardized manner. Training will include practice in standard operating procedures (SOPs) as documented in a field training and operations manual. This manual will not be included in the logistics plan, but will be developed as a separate implementation document. The manual will include protocols for measurements, sample collection, sample handling and processing, sample shipment, data recording, associated QA and quality control (QC) issues, safety issues, communications, and preventative maintenance. At the end of training sessions and at debriefings at the end of surveys, the manual will be reviewed and a formal questionnaire for each section will used to document changes that are needed in the SOP for future surveys.

A training program plan will be developed prior to the start of any field or laboratory operation. Training will include practice with each of the SOPs. Specialized training such as safety training, training for leadership personnel, or instruction on instrument operation or maintenance will be addressed. If outside organizations are needed for any aspect of training (for example, the American Red Cross for first aid/cardiopulmonary resuscitation (CPR) instruction), their services will be arranged. Participants will be evaluated for competency following training.

As the program expands to new regions, many trainers will be needed to train all the field crews. Pre-training sessions, which will be designed to maintain consistency across and within regions will be needed to "train trainers". Logistics personnel will be responsible for locating training sites and facilitating training sessions.

9.4.7 Communications

The logistics plan will establish efficient communications methods to ensure smooth operation of field sampling, laboratory analyses, and data and sample tracking activ-

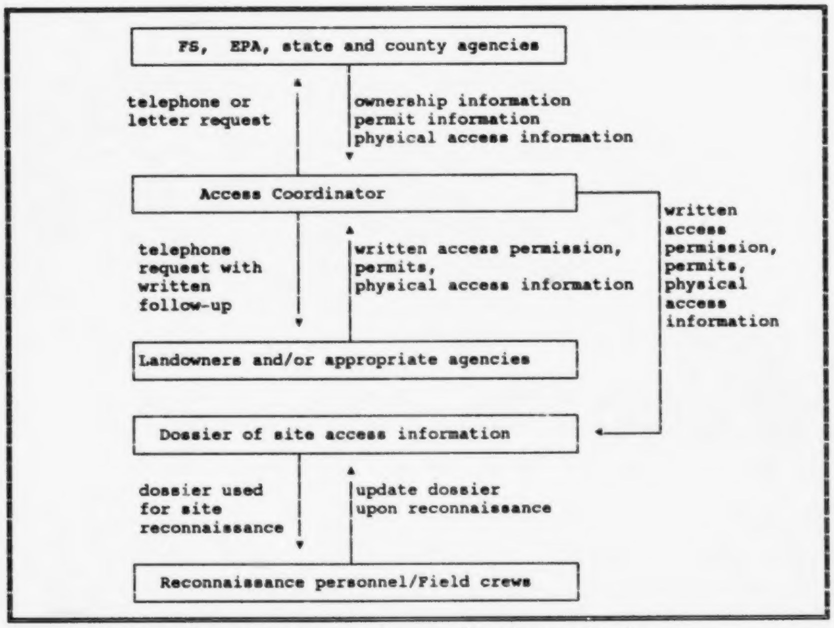

FS, EPA, state and county agencies
telephone or letter request
ownership information
permit information
physical access information
Access Coordinator
telephone request with written follow-up
written access permission, permits, physical access information
written access permission, permits, physical access information
Landowners and/or appropriate agencies
Dossier of site access information
dossier used for site reconnaissance
update dossier upon reconnaissance
Reconnaissance personnel/Field crews

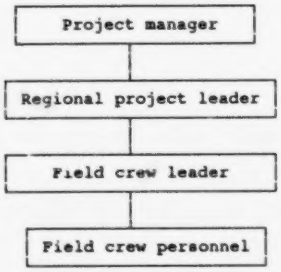
Figure 9.5. Example of a sampling site access plan.

ities. All communications lines required for science, logistics, and safety (Figure 9.6) will be determined. If working with other agencies, additional communications lines to disseminate information to these groups will be needed.

The communications plan will describe methods for tracking sample shipments to laboratories and for sending and tracking data. It will also provide a mechanism for field crews to acquire information from laboratories, data management staff, and QA staff about problems with data collection or sample handling so that the problems will not recur.

9.4.7.1 Line of Communication

The basic line of communication is illustrated as follows:


Project manager
Regional project leader
Field crew leader
Field crew personnel

Project Managers

Project managers are responsible for the dissemination of information vital to the project (i.e., protocol changes, sampling schedule changes, etc.) and will require progress reports on all aspects of the project.

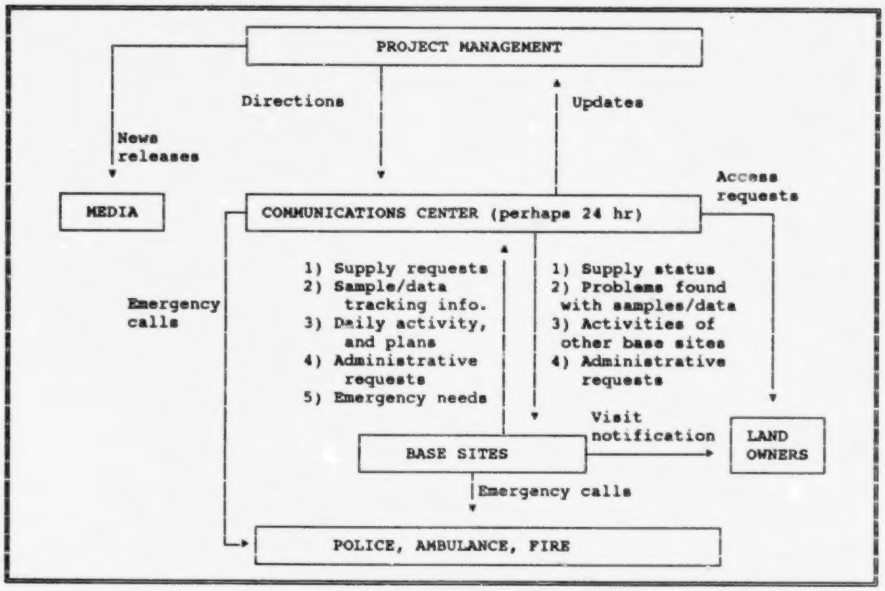

PROJECT MANAGEMENT
Directions
Updates
News releases
MEDIA
COMMUNICATIONS CENTER (perhaps 24 hr)
Access requests
Emergency calls
1) Supply requests
2) Sample/data tracking info.
3) Daily activity, and plans
4) Administrative requests
5) Emergency needs
1) Supply status
2) Problems found with samples/data
3) Activities of other base sites
4) Administrative requests
Visit notification
LAND OWNERS
BASE SITES
Emergency calls
POLICE, AMBULANCE, FIRE

Figure 9.6. Example of a communications plan.

Regional Project Leads

The regional project lead is responsible for relaying information to the project managers and other technical support leads and from field crew leaders (Figure 9.7). The regional lead disseminates information back to these groups and may need to contact land owners or emergency services. Regional project leads will be available for phone or emergency communication during sampling hours. However, a 24-hour line of communication with the regional project lead must be established. This could be accomplished by using phone recorders, electronic mail, or GIS capabilities.

Field Crew Leader

The field crew leader must inform regional project leaders about sampling progress and problems or emergencies that occur in the field. Field crew leaders are responsible for the direct communication of emergencies to the appropriate authorities. If injured, their duty will be transferred to one of the field crew members. The field crew leader will submit weekly travel itineraries to the regional project leaders and is responsible for disseminating information to field crew personnel (i.e., status of sample shipments, data discrepancies, supply disposition, etc.).

Field Crew Personnel

Field crew personnel are responsible for their sampling assignments. They must report to the field crew leader to establish an efficient relay of information on progress, problems, or emergencies occurring in the field.

Conference Calls

As illustrated in Figure 9.7, the regional project leaders link the field crew leader with project managers, other technical leads, and various groups. As problems occur in the field or as protocols change, it is important that decisions are consistent for all field crews and regions. Therefore, a weekly conference call will enable technical leads, regional leads, and

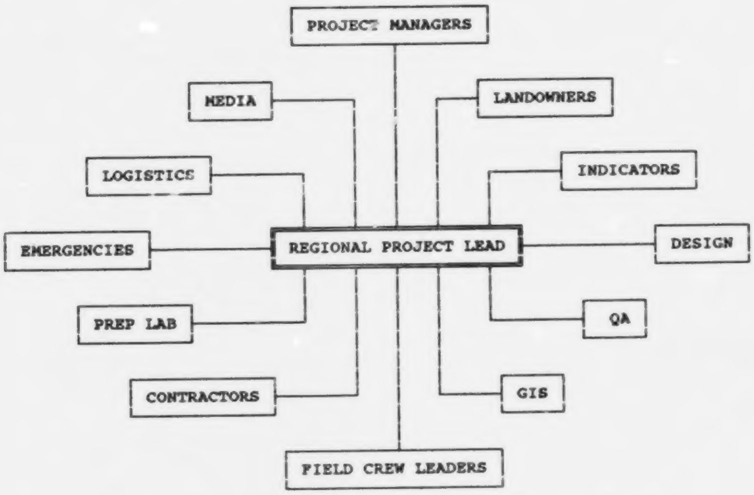


Figure 9.7 Flow of information to and from regional project leads.

project managers to discuss progress on all operational phases, problems, and protocol changes.

9.4.7.2 Geographical Information Systems (GIS)

The GIS group can assist the project by locating facilities and services that may be necessary for field crews, including hardware stores, hotels, express mail, automotive repair shops, hospitals, and fire stations.

The GIS group has used a software package called Business LINE® which provides business listings and summary reports for 7.6 million business establishments throughout the United States. Latitudes, longitudes, geocodes, addresses, and telephone numbers are included in this data base. Maps of each hexagon or state can be produced that include location of important establishments.

9.4.8 Contracting

Many operations within the FHM program will require some form of contracting. Contracting may be required for phases of field sampling, sample preparation, and sample analysis.

9.4.8.1 Contracting Mechanisms

The following types of contracting mechanisms can be used to acquire services for EMAP-Forests:

- Federal government acquisition.
- Fixed price contract (IFB).
- Competition negotiation (RFP).
- Special analytical services.
- Interagency agreements.
- Cooperative agreements.
- Subcontracts.

9.4.9 Safety

The safety plan will consider preventive safety measures and emergency action procedures.

Clothing and other equipment will be discussed in the safety plan and criteria used for selection of safety gear for field personnel will be explained. Other sections of the logistics plan (training, waste disposal) will outline additional preventive safety measures.

Information on field personnel and their travel itineraries (Table 9.4) will be compiled. A person responsible for maintaining this information will be identified.

Emergency action plans will be developed. The American Red Cross principles of first aid/CPR will be used as a guideline for the initial treatment and evaluation of personnel in emergencies. Criteria and methods will be developed for initiating search and rescue operations. The communications plan will indicate who will be contacted during emergencies.

Table 9.4. Safety information to be logged by field personnel.

Travel itinerary
 roads to be travelled, order
 flight plan
 coordinates expected to be visited, order
 time left base site
 estimated time of return

Medical information
 known allergies
 existing conditions (eg., heart disease, diabetes)

Personal contacts (i.e., immediate family)
 addresses
 telephone numbers

Personal descriptions
 color and types of clothing worn
 height and weight
 hair, eye, and skin color
 age
 vehicle used and its description

9.4.10 Scheduling

The sampling design task group will provide various input parameters: the geographical area to be studied, the sampling site locations, and the sampling index period. The methods task group will provide other required information such as the sampling and transportation equipment to be used and the required sample holding times. Based on the design and methods requirements, an efficient sampling schedule will be developed.

Geography will be considered when preparing the sampling schedule. The locations of sampling sites in relation to each other and to other points of interest will determine how much time and fuel will be required to travel to and from sampling sites. The distribution of sampling sites relative to refueling stations, base sites, and courier services will be determined.

"Down time" will be accounted for in the schedule by considering typical climatological conditions for the area during the sampling window. Precipitation, cloud cover, temperature, and winds can affect the quality of samples and sampling site accessibility.

The difficulty of site access will also be of concern. Physical constraints include mountains, brush, soft substrate (mud or marsh), and the lack of paved roadways. Legal constraints include lack of access permission and any conditions imposed by landowners. Parklands, wilderness areas, or publicly owned water supplies may forbid motorized access. Military reservations may be restricted or require escorts.

When the above factors are examined, a list of potential schedules and potential base sites can be created (Figure 9.8).

Schedules will also be developed for other data collection activities such as sample preparation and laboratory analysis. Volume of samples and turnaround time for reports will affect schedules and must be determined prior to field activities to secure proper facilities to handle the activities.

9.4.11 Quality Assurance/Quality Control

In accordance with the QA plan, there will be regular site audits to assure that field personnel are operating according to protocols established by the Field Training and Operations Manual. The logistics plan will indicate who will audit and when audits will occur. If QA objectives require field crews to be unaware of impending audits, then the logistics plan will provide windows of appropriate times for audits. The logistics plan will also describe how audit comments will be addressed and provide a mechanism to correct protocols.

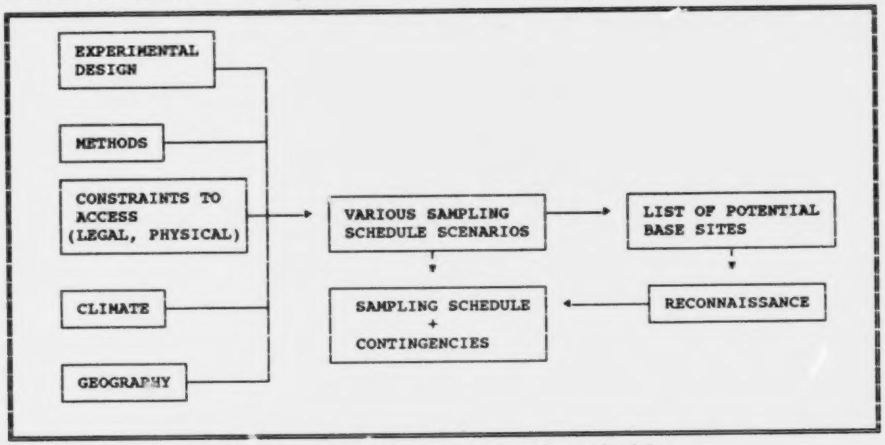

EXPERIMENTAL DESIGN
METHODS
CONSTRAINTS TO ACCESS (LEGAL, PHYSICAL)
CLIMATE
GEOGRAPHY
VARIOUS SAMPLING SCHEDULE SCENARIOS
LIST OF POTENTIAL BASE SITES
SAMPLING SCHEDULE + CONTINGENCIES
RECONNAISSANCE

Figure 9.8. Development of a sampling schedule.

9.4.12 Information Management

Four aspects of information management will be discussed within the logistics plan:

1) Data recording.
2) Data transfer.
3) Data security.
4) QA.

The data management plan will describe a standard method for recording data (see Section 10.3.1.3.2). The logistics plan will address who will record the data. It will also address who will develop the forms and how the forms will be printed. If software is to be used, the plan will address who will develop the entry programs and how they will be set up on hardware.

Data transfer mechanisms from temporary field data bases to the central data base will be developed (see Section 10.3.1.4). The plan will indicate when data will be sent, how often it will be sent, and what security measures will be taken to ensure that data will not be lost (i.e., properly backing-up data).

The verification procedures will be described. The data review process will be established. This process includes how and when the data will be reviewed and how the reviewer(s) will signify that the review has been completed.

A computerized barcode sample tracking system will be developed (see Section 10.3.1.5). This will make sample tracking and chain-of-custody more efficient and reliable. A similar system will be used to inventory equipment and consumables.

9.4.13 Review/Recommendations

The logistics activities will be summarized each year of the study. Discussions will include debriefing sessions, resolution of problems, and planning activities for the following year.

9.4.14 Inventory/Storage

After an operational phase is completed, the equipment and supplies used during the phase will be inventoried and examined for damage. Bar code readers, used for sample tracking, will be used to inventory and track equipment. Equipment and consumables will be ordered for the next year's activities and stored at regional locations.

10 STRATEGY FOR THE INFORMATION MANAGEMENT SYSTEM

This chapter describes the information management (IM) system for a National Forest Health Monitoring (FHM) program that is achievable five years from now. The current IM system is embedded in the description of the future IM system. The steps necessary to move from the present system to the future are presented in this section. The level of detail reflects the level of uncertainty concerning the future direction of FHM and the future of technology. Flexibility is a key concept in the IM system. An IM system that can not or will not adapt to change will be obsolete before it is implemented.

10.1 INTRODUCTION TO INFORMATION MANAGEMENT

Information management supports and facilitates many aspects of environmental monitoring. The IM personnel work with the technical directors, project managers, logistics staff, quality assurance/quality control (QA/QC) personnel and scientists throughout the FHM project. This starts with planning and coordination to assure an IM system that is responsive to overall project needs. During implementation and the operational phases of data collection and transfer, software systems will be in place to support the timely acquisition of data into the IM system. After data collection, IM supports the scientists working on integration and analysis of data and presentation and reporting of results. IM will also support the dissemination of data and information to users outside of the FHM program.

The FHM IM system will be distributed with nodes on both EPA and FS computer networks. A user will be able to connect to the FHM data base system and access data without knowledge of the location of those data. Eventually this networked IM system will include computer networks from other agencies participating in FHM such as the National Park Service (NPS), Bureau of Land Management (BLM), states, and universities.

A key element in the FHM IM system is the Forest Information Center (FIC). The FIC, staffed by personnel from all agencies participating in FHM, is the nexus for software development, data collection (both FHM-generated and historical data), data cataloging, data processing, and data dissemination. The FIC staff will work with appropriate personnel in the FS and the EPA to assure that the automated data processing (ADP) requirements of FHM are met.

10.2 GOALS AND OBJECTIVES

The design and development of the IM program is guided by the following goals:

- Assure that the data in the system are of the highest possible quality.
- Assure that FHM scientists have access to the data as quickly as possible.
- Make the data available to users both within the project and outside the FHM group.

To achieve the above goals, an IM program will be developed to meet the following objectives:

- Design an IM program to be responsive to user requirements from within and outside the FHM program.
- Commit to achieving complete data collection and transfer electronically.
- Ensure access to FHM-generated data, auxiliary data, and historical data.
- Provide an IM program that effectively collects, processes, documents, stores, catalogs, and distributes the FHM data within accepted time frames.
- Develop a flexible IM program that can adapt to the program's future needs.

- Develop an integrated IM program that provides access to GIS systems, other EMAP and FS monitoring components, and other programs.
- Develop a system that is responsive to the needs of the national FHM program, but is flexible enough to accommodate regional differences.
- Provide training and support to the field crews and users of the FHM IM system.

10.3 DESIGN OF THE FHM IM SYSTEM

The IM system for the FHM program will have two major components: (1) a field and laboratory data collection system, and (2) a data management system. The field and laboratory system handles data coming into the FIC. The data management system handles data in the FIC and distributes data to the users.

10.3.1 Field and Laboratory Systems

The field and laboratory systems provide input to the FHM FIC. These systems have close ties to the cross-cutting activities of QA/QC and logistics. The objectives of the field and laboratory systems are twofold: (1) to develop a system to ensure that Measurement Quality Objectives (MQOs) are satisfied, and (2) to ensure that data are sent to the FIC in a timely manner. This mandates electronic data collection in the field and the laboratory and electronic data transfer to and from the FIC. These systems must be flexible enough to accommodate changes in data requirements, indicators, and technology.

Verification checks are placed as close to the point of data entry as possible in the field and the laboratory. Close cooperation with the QA staff will be essential in the development of the computerized verification checks.

Electronic sample, shipment, and crew tracking will be used to give project managers daily updates of field and laboratory activities. These tracking systems will be developed in conjunction with the logistics staff.

10.3.1.1 Field Crew Hardware and Software

Field crew equipment will include portable data recorders (PDRs), laptop computers, portable printers, global positioning system (GPS) hardware, and bar code readers. The first three items in the list were used in the 1990 field season. Except for the laptop and the printer, which remain in the motel room, all the equipment listed is used in the field.

10.3.1.2 Field Logistics Data Base (not implemented in 1990)

A logistics data base with a user-friendly interface will be installed on the laptop computers to simplify field logistics. Information describing sample site locations and logistics information will be entered into a geographic information system (GIS) data base. The GIS system will produce maps showing the locations of sample sites and support services. With these data, the crew will easily be able to locate sample sites, express mail facilities, motels, airports, hospitals, repair centers, etc. Sampling site information will include location of the site, location of the starting point, field measurements to be taken, and samples to be collected.

10.3.1.3 PDR Programs

The EMAP-Forests indicators are dependent on field measurements such as forest mensuration data, pedon descriptions, and visual damage data. To ensure that field data are of the highest quality possible, EMAP-Forests will be committed to electronic data collection.

To facilitate electronic data collection, each field crew will have one or more PDRs. The PDR is a rugged field computer. The PDR currently used by EMAP-Forests is MS-DOS compatible, which allows for flexibility in programming. Custom software, written in C and BASIC, was developed for the PDR for use in the 1990 field season. The current software will be refined and new programs will be developed for the PDR as the FHM program continues. The PDR programs will include the GPS data collection programs, sample tracking information, and communications. A user-friendly menu will allow the crew to choose the appropriate program. Sections 10.3.1.3.1-10.3.1.3.3 provide details about the programs envisioned for use on the PDR.

10.3.1.3.1 Global Positioning System (not implemented in 1990)

The GPS will interface with software on the PDR, allowing the crew to determine their field position within tens of meters. Software will be written to utilize the GPS data to guide the crew to the plot. This system will help crews find new as well as established plots.

10.3.1.3.2 Field Data Collection Programs (implemented in 1990)

Data entry will be performed directly on the PDR in the field. Paper forms will be used only for back-up in case the PDR fails in the field. A spare set of PDRs will be available; these can be shipped via express mail to a crew within 24 hours.

The PDR will have various data collection programs. Menu choices, based on the data requirements of the current indicators, will include soil pedon descriptions, forest mensuration (including visual damage data), vertical vegetation profile, and ceptometer data transfer.

If, for example, the user chooses the forest mensuration data collection program, an electronic tally sheet will be displayed on the PDR screen.

Using electronic data entry allows for QA checks at the point of data entry. These QA checks, which include range checks, validity checks, and logic checks, will be designed in close cooperation with the QA staff and the indicator leads. Data from previous years will be loaded on the PDR for further QA checks. For example, the user will be notified if the diameter of a tree is significantly smaller this year than it was in a previous survey. Additionally, data from previous surveys can help the field crews locate specific trees. The distance and direction to a tree will ensure that the same tree is sampled in all surveys, a requirement for some indicators. This feature was not implemented in 1990.

10.3.1.3.3 Sample Tracking on PDR (not implemented in 1990)

Many types of samples will be collected in the field. Currently, these include soil, root, foliar, and increment cores. The field crews must be sure that all necessary samples are collected and that samples are correctly identified and tracked. A bar-coding system will link data on the PDR to samples collected in the field. This will permit a relational join between the sample ID and data in the PDR. The system will check that all samples have been collected before the crew leaves the field. Sample tracking is described in more detail in Section 10.3.1.5.

10.3.1.4 Field Communications System (partially implemented in 1990)

When fully implemented, the communications systems will allow for two-way communications between field crews and the FHM FIC. Data and tracking information will be uploaded from the crews to the FIC. Messages, data, and program updates will be sent from the FIC to the crews. In 1990 communications were unidirectional, from field crews to the FIC.

10.3.1.5 Computerized Shipment Tracking (not implemented in 1990)

The field crews will collect a plethora of samples, many of which are perishable, requiring proper handling and quick shipment to the laboratory. A computerized sample and shipment tracking system that utilizes bar codes is necessary to ensure that samples get to the proper laboratory in a timely manner. The field crews will have pre-printed sample labels with bar codes. When a sample is collected, data about the sample will be entered in the PDR. The sample will be labeled, the bar code scanned, and the sample number recorded on the PDR. Before leaving the field, a program on the PDR will check that all samples have been collected.

When the data from the PDR are uploaded to the laptop, the sample tracking data base on the laptop will automatically be updated. The crew will use the bar code reader to scan the samples as they are packing the shipment cases. The system will:

- Ensure that the correct samples are packed together.
- Ensure that samples are shipped to the correct laboratory.
- Check that all samples have been shipped.
- Provide information about special handling required.

After all samples are ready for shipment, the crew will enter data about the shipment on the laptop. These data include: shipment number, carrier name, air bill number, destination laboratory, and estimated time of arrival at the laboratory. These data are entered into the tracking data base which is sent to the FIC and then to the receiving facility.

This communication system also allows crew tracking. A crew tracking data base, including location of crews, locations sampled, data collected, samples collected, and shipments sent, will be updated daily.

10.3.2 Laboratory Systems (partially implemented in 1990)

The FHM program will employ a variety of laboratories for processing different sample types. Computerized laboratory sample tracking, verification, and communications systems will be used by the laboratories employed by the FHM program. The FHM program will have two types of laboratories, preparatory and analytical. This section describes the components common to both laboratory types.

Each laboratory will have an IBM-compatible computer with a modem and bar code reader. The FHM laboratory system software will be installed on the computer. The tracking portion of the system will interface with the tracking system described above to create a complete sample trail from field to laboratory. The verification portion of the program ensures that results from the laboratory meet the quality standards of the FHM program.

The communications are similar to the field system. The laboratory will send the following information to the FIC via modem:

- Results, including QA/QC data, since last upload.
- Samples received at the laboratory.
- Samples shipped from the laboratory (for preparatory laboratories only).
- Messages from the laboratory to the central system.
- Tracking data.

The following information will be sent from the FIC to the laboratory:

- The tracking data base.
- Software updates, when required.
- Messages from the FIC to the laboratory.

Each laboratory will have a bar code reader. As shipments arrive at the laboratory, the bar code label on each sample will be scanned. Those data will be compared against the tracking data base that was downloaded from the FIC.

10.3.2.1 Preparatory Laboratory Systems (partially implemented in 1990)

Preparatory laboratories receive field samples, process the samples, then ship the samples to analytical laboratories. A data base will be maintained based on the information entered in the preparatory laboratory. The data base will relate batch numbers to sample numbers and will record data that describes archived samples.

10.3.3 Data Management System

This data management section envisions a five-year scenario. This scenario includes the assumptions that a high speed connection between the EPA and FS computer networks and a relational data base management system (RDBMS) that is compatible between the two agencies are in place.

The core of the distributed FHM data management system is the FHM FIC. As referenced in this document, the FIC is a logical concept; the physical structure of the FIC will be determined after detailed design work is completed. The FIC will be staffed by both EPA and FS personnel and will support the exchange of data with other agencies and organizations. Information management personnel are responsible for maintaining a comprehensive data inventory, data set index, code libraries, and data dictionary. They will also maintain and disseminate FHM data and ensure that appropriate data are incorporated into the FIC.

10.3.3.1 Data Types

The FHM IM system will contain data generated by the FHM program and data from outside sources. The following types of data will be maintained by the FIC:

- Project management and logistics data.
- Raw data files.
- Summarized data.
- QA/QC data.
- Laboratory data and associated QA/QC data.
- Spatial data in GIS format.
- Historical data.
- Pointers to auxiliary data (e.g., climate data).

10.3.3.2 Users

Users of FHM data will include the following four groups.

Group I Users: FHM Core Group - Responsible for day-to-day field operations and data verification and validation activities. The group will include field crews, logistics staff, QA/QC staff, IM staff, indicator leads, and the technical directors of the FHM program. Both FS and EPA staff are in this group.

Requirements - This group will need to have access to a comprehensive data set, including project management information, sample and shipment tracking, raw data files, QA/QC reports, logistics, summary reports, and verified and validated data sets.

Timing of Access - This group will require access to the data on a real time basis. The data need not be quality assured prior to access. All raw data used by this group must be used with the understanding that the data have not been verified or validated. This group needs access to all data described in the other categories.

Group II Users: FHM Team - Individuals and groups who will participate in the FHM effort but will not be active in the day-to-day operations of the field programs or the data verification and validation processes. These participants will include FHM staff involved in reporting, the FHM Integration and Analysis Team, GIS support personnel, FHM design and statistical staff, and program reviewers.

Requirements - This group will require access to summary information regarding logistics, project management, and QA/QC. They will also require access to some validated and verified raw data files but will not require real time access to the data.

Timing of Access - Group II users will require data one month from the time of collection.

Group III Users: Inter-Agency Research Group - Includes all researchers who will be active in the design, implementation, and analysis of the national EMAP program, the other FS-FHM groups, and scientists from other participating agencies. These individuals will include members of other EMAP resource groups, EMAP cross-cutting groups, the FS evaluation monitoring team, and the FS research monitoring team.

Requirements - This group will require final summaries regarding logistics, project management, and QA/QC. They will require access to some validated and verified raw data files. Document summaries with interpretation and graphic outputs will be most useful.

Timing of Access - Group III users will require data approximately six months from the time of data collection.

Group IV Users: Other Users - Includes all potential users outside of those listed above. This group will include state and federal agencies, universities, research organizations, citizen's groups, administrators, and legislators.

Requirements - This group will require access to validated and verified data including QA/QC data that is integrated to the plot level. They will need summarized characterization data for each plot sampled and access to an index of available data. They will also require access to some validated and verified raw data files. Document summaries with interpretation and graphic outputs will be most useful.

Timing of Access - Group IV users will require data one year from data collection.

10.3.3.3 Data Base Access

Users on either the EPA or FS computer networks will be able to access the FHM IM system directly through the networks. Users who are off the network can access the system through a dial-up line into the system. Users in Groups I and II (see Section 10.3.3.2) will access the data through the FHM IM system. Users in Groups III and IV may have the option of accessing the FHM IM system, but it is more likely that they will use the EMAP-wide EIC.

A user-friendly interface will guide the user to required data. A data catalog and a data dictionary will detail the data available through the data base system. For wide distribution of the data, use of a commercial service such as Compuserve will be explored. At periodic intervals, the data in the data bases will be published on CD-ROM.

10.3.3.4 Data Base Security

The four user groups will have different access privileges to the data bases. Until the data have been verified and validated, very strict security measures will be employed. Only members of Group I, the core group, will have access to raw data from the field and the laboratories and project management data. During the QA/QC process, only the IM staff will be allowed to change the data bases. If discrepancies are found during the QA checks, those data will be communicated to the IM staff. The IM staff will update the data bases and record the change, the person requesting the change, and the reason for the change in a data base. This is to ensure that there is only one official version of the data base that is maintained by the IM staff.

After the data bases have passed QA/QC, the security will be changed so that members of Group II (the FHM analysts) will have access to the data. At this point, members of Group III can have access to the data with permission of the TD. After the yearly statistical summaries have been published, the data will be made available to other users. At this point, the FHM data will be made available to the EMAP-wide EIC.

10.3.3.5 Data Confidentiality

Certain types of data, both FHM collected and from external sources, may have to remain confidential. Locational data are the most likely candidates for confidentiality. These data include FHM plot location, location of plots in other data bases used by the FHM program (e.g. FIA plot locations), and locations of rare and endangered species.

The GIS representations of point data will be "fuzzed" to hide the exact locations of plots, or the data will be represented on a regional basis to hide the exact plot locations. The locational data in the public data base will be reported at the Tier 1 hexagon center level. Analysts outside of Group III who need exact locational data will need written permission from the senior administrators of the FHM program and will be required to sign a non-disclosure document.

10.3.3.6 Data Base Management System

The FHM data base management system will include a data set index (DSI) also known as a data catalog, a data dictionary, code look-up tables, and a user-friendly interface. An RDBMS will be the engine of the system.

The DSI will provide users with important information about the contents of each data set. It will also describe how to access a particular data set. The DSI will also store a catalog of FHM-generated, historical, and auxiliary data.

The on-line data dictionary will provide users with information about parameters stored in the data bases.

10.3.3.7 Yearly Statistical Summaries

Standardized, yearly, data statistical summaries will be one product of the FHM program. Standard software will be developed to automatically produce the tables, graphs, and maps that go into the yearly statistical summaries.

10.3.3.8 GIS Interface

A major requirement of the FHM FIC will be to create maps and perform geographically-based analyses. Therefore, the data generated for FHM will be referenced to a spatial entity such as a latitude and longitude. Spatial analyses will be accomplished using ARC/INFO, a GIS that is used throughout the EPA and the FS. ARC/INFO is not user-friendly. Therefore, user-friendly interfaces for routine data analysis and display will be developed by the FIC.

10.3.3.9 EMAP Information Center

The EIC will be the entry point to EMAP data bases. The EIC will allow users to access data from the EMAP resource groups and cross-cutting activities.

For the overall EMAP goals to be met, scientists must have access to all data collected in connection with EMAP data, including FHM data. The design of the FHM IM system must be compatible with the EIC design to allow other EIC users access to the data.

10.4 STRATEGY TO MOVE TOWARD THE FHM IM SYSTEM

This section outlines what is needed to make the preceding vision of the FHM IM system a reality. Most importantly, the plan for the IM program must undergo continual review and update.

10.4.1 Recognition of the FHM as a New and Different Program

All participants must recognize the FHM as a new program. It may have its roots in other programs, such as FIA, FPM, Forest Response Program (FRP), and the Direct/Delayed Response Project (DDRP), but FHM is fundamentally a new program with a new set of goals and objectives. The program should borrow the good points from its ancestors, but it should look beyond its antecedents to determine its own future. This is especially true of IM. The IM goals of the FHM program may be best served by establishing a new data processing program.

10.4.2 Commitment to an Interagency IM Program

All participating agencies, EPA, FS, NPS, and others, must make a commitment to IM. All parties must realize that without good cooperative IM at all levels, from the field to data bases, the FHM program will likely fail. This commitment includes adequate funding, adequate staffing, and the recognition that difficult decisions must be made. The program must recognize that there are no EPA data and there are no FS data; there are FHM data that will be shared with all participants in the program.

The FIC will be the focal point for data collection and dissemination. The FIC will receive data from all field locations and make data available to users of all agencies concerned after QA/QC is complete. The FIC will manage data on a system that ties the EPA and FS computer networks together.

A phased approach to the development of the IM program will be needed. The current level of resources, technology, and interagency cooperation dictates that for the next several years each agency will maintain separate data base systems. Commitment to and planning for the FIC should begin immediately.

10.4.3 Public Access to the Data

The FHM program must make a strong commitment to making the data available to the public. After the data have been through the verification and validation processes and the yearly statistical summaries have been produced, the data should be available to all interested users.

10.4.4 Interactions with the EMAP Information Center (EIC)

EMAP-Forests must adhere to the requirements of EMAP. One such requirement is having all EMAP data accessible through the EIC. All participating agencies must agree with the policy that data collected in connection with EMAP-Forests will be made available to the EIC. Release of the data to the EIC will be subject to data security and confidentiality constraints (see Section 10.3).

10.4.5 Standards

Standards are necessary for FHM to be a truly national program. The FHM program and its IM system must be flexible enough to accommodate regional differences, but at the same time be comparable at some level throughout the country. Standards that are used throughout the program are necessary to meet that objective. An interagency work group should be formed to resolve standards issues. For example:

- Codes - Standards for codes that are used across the country, such as species, must be adopted. The FIA has a standard set of some codes. It is recommended that those codes be adopted.
- Computational Algorithms - A standard set of FHM computational algorithms that correspond to ecological, not political, boundaries must be established. Post-stratification along political boundaries will always be possible, if required.
- PDRs - PDRs must be standardized to the extent that all those used by FHM will run the same programs without modifications.
- PDR Software - The same software should be used on all the PDRs used by FHM. The software should be flexible to allow for regional differences.
- Measurement Units - The FHM should use the same measurement units, preferably SI, in all regions of the country.
- Word processing software - A standard word processing program should be adopted for producing reports and documents. If institutional constraints prohibit this, a standard interchange format should be adopted.

10.4.6 Data Sharing and Access

All agencies concerned must come to an agreement on data access. One proposal for data access is given in section 10.3.3.2 of this document.

If this model of data sharing is not acceptable to all participants, an interagency committee should be formed to draft an alternative policy. A clearly stated policy on data access should be adopted for the entire FHM program.

10.4.7 Staffing

The FHM IM program needs a full time, quality staff of adequate size. The FIC minimum staff and their functions include:

- Information Manager - responsible for system design, management of the information staff, liaison with other ecosystems and agencies.
- Systems Programmer(s) - responsible for development of the software for the field

systems, communications, and data analysis.

- Data Base Manager/Programmer(s) - responsible for data base programming, assists the Information Manager in data base design and works with the other staff in satisfying users data requests.
- Data Clerk(s) - responsible for documenting FHM data sets including historical data obtained from other agencies, responding to data requests from members of the FHM team and routinely processing FHM-generated data.

An interagency programming team, using state-of-the-art programming tools, such as object-oriented programming, should be formed to develop flexible programs for FHM. The FHM program can use existing software for several more years, but FHM can not afford to institutionalize software that does not have the ability to evolve with the program.

10.4.8 Interagency Computer Links

For FHM to function efficiently, there must be a link between the computer networks of all participating agencies. These agencies include the EPA, FS, NPS, BLM, and possibly others. The link should start with an EPA/FS connection, then progress to other agencies. The interagency links will provide services such as E-Mail capability, file transfer, and data base access to all participants across the FHM program. Additionally, links to other networks such as Bitnet, Internet, and LTERnet should be explored. Those additional links will allow easy access to university cooperators.

10.4.9 User Needs Analysis

The FHM Information System must be responsive to users' needs. A study must be undertaken to identify categories of potential users of FHM data. After users have been identified, a user needs analysis will be performed. Users will be queried to determine the types of data needed, the modes of access, and the interfaces desired. Once the users and their needs have been identified, a reevaluation of the user categories presented in section 10.3.3.2 will be undertaken. The data compiled in the user needs analysis will be one input in the design of the FHM IM system.

11 STRATEGY FOR REPORTING

In contrast to the term "assessment", which refers to the intellectual synthesis and interpretation of forest environmental data (Section 7), "reporting" refers to the mechanical aspects of document scheduling, production, review, and clearance. This chapter considers all documents produced by the interagency Forest Health Monitoring (FHM) program and focuses on the reports and roles of EMAP-Forests.

Reporting activities operate simultaneously within several programs and must serve many needs. The reporting strategy of EMAP-Forests is coordinated by EMAP and is implemented in cooperation with the Forest Service (FS) and other agencies that also produce monitoring reports. Teams of analysts are comprised of individuals from several organizations. Success within these multiple contexts requires cooperation among agencies and individual participants, and division of labor is an essential ingredient of the strategy.

11.1 CURRENT STATUS OF REPORTING

EMAP-Forests operates as a national reporting unit, with specific laboratory roles assigned according to the overall EMAP scheme (i.e., design, statistics, and indicators at ERL-C; integration, assessment, weather, air quality, and pollution deposition at AREAL-RTP; logistics, quality assurance, and information management at EMSL-LV). Reports are coordinated with national program counterparts in the FS. EMAP-Forests does not have regional reporting capabilities, except that national staff participate in some regional reports prepared by FS regions.

In contrast, the FS operates as regional reporting units, making use of EMAP-Forests national staff to produce regional reports. Currently, there is not an identified national reporting responsibility within the FS.

There is not a formal interagency agreement concerning the preparation, publication, and distribution of reports; however, each agency has identified the types of reports that are expected.

11.2 REPORTING DESCRIPTIONS

This section describes the purpose, scope, scheduling, and review and clearance procedures for various reports. These descriptions are based on earlier EMAP plans and on the summaries of the "Analysis and Assessment" and the "Reporting" work groups at the Joint EPA/USDA-FS Meeting on Forest Health Monitoring Coordination (January 23-24, 1990, Research Triangle Park, NC). The characteristics and purposes of the reports are summarized in Tables 11.1 and 11.2. A logical sequence of the reports considered in this chapter is shown in Figure 11.1.

11.2.1 Types of Reports

Reports delineated in this section include plans, operations reports, data base summaries, data quality reports, statistical summaries, interpretive reports, and technical proceedings. Plans describe the rationale and intentions of the monitoring program and are a focal point for peer and management reviews. Operations reports summarize the actual operations of the monitoring program. Data base summaries and data quality reports document the existence and quality of the data that are collected. Statistical summaries provide timely descriptions of regional status and trends in forest condition in terms of a few key indicators. Interpretive reports address specific environmental issues, incorporate additional data and detail in the analysis of status and trends, and consider linkages between forests and other

Table 11.1 Summary of reports to be produced by the interagency forest monitoring program.

Report type	Freqency/ Scheduling	Authors/ Publishers
Interagency Monitoring Plan	once/ spring '92	multi-agency/ unknown
Interagency QAPP spring '92	once/ EPA	multi-agency/
Research Plan as needed	varies/ varies	varies/
Regional Work Plan	annual/ June 30[a]	multi-agency/ FS regions
Regional QAPjP June 30[a]	annual/ EPA	multi-agency/
Regional Operations Report	annual/ January 30[b]	multi-agency/ FS regions
National Operations Report	annual/ March 30[b]	multi-agency/ EPA
National Data Base Summary	annual/ June 30[b]	EPA/ EPA
National Data Quality Report	annual/ June 30[b]	EPA/ EPA
Regional Statistical Summary	annual/ September 30[b]	multi-agency/ FS regions
National Statistical Summary	annual/ September 30[b]	multi-agency/ EPA
Regional Interpretive Report	3-5 yr./ FS region	multi-agency/
National Interpretive Report	3 yr.	multi-agency/ EPA

(Continued)

Table 11.1 (Continued)

Report type	Freqency/ Scheduling	Authors/ Publishers
MAP Integrated Assessments	3-yr.	EPA/ EPA
Proceedings		multi-agency/ FS national

[a] In the year prior to the year of data collection.
[b] In the year following the year of data collection.

Table 11.2 Summary of purposes of reports to be produced by the interagency forest monitoring program.

Report Type	Brief statement of purpose
Interagency Monitoring Plan	Basis of Interagency Agreement (IAG) between USDA-FS and EPA for monitoring rationale, approach, and implementation of interagency monitoring program
Interagency QAPP	Basis for interagency Quality Assurance (QA) program
Research Plan	Initiate improvement of monitoring capabilities by exploring, for example, alternate designs, indicators, and assessment models
Regional Work Plan	Describe program management, logistics, QA, information management, and reporting procedures for monitoring
Regional QAPjP	Articulation of QA activities for each region
Regional Operations Report	Summarize operational experiences and accomplishments and recommend changes to implementation
National Operations Report	Same as regional operations report
Data base Summary	Signal agreement on, document contents of, and describe access to the forest data base
Data Quality Report	Document the quality of data contained in the forest data base

(Continued)

Table 11.2 (Continued)

Report Type	Brief statement of purpose
Regional Statistical Summary	Provide timely summary of status and trends in forest condition; provide regional authorship opportunity
National Statistical Summary	Provide timely national summary of status and trends in forest condition
Regional Interpretive Report	Investigate status and trends in relation to regional environmental issues and policies
National Interpretive Report	Investigate status and trends in relation to national environmental issues and policies
Report title	Brief statement of purpose
EMAP Integrated Assessments	Investigate status and trends of forest condition in relation to status and trends of other ecosystems
Proceedings	Provide publication opportunity and document monitoring procedures

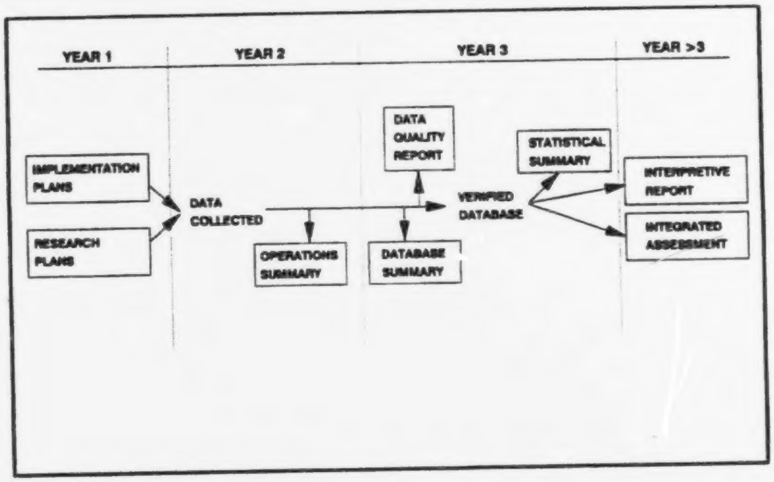

YEAR 1
YEAR 2
YEAR 3
YEAR >3
IMPLEMENTATION PLANS
RESEARCH PLANS
DATA COLLECTED
OPERATIONS SUMMARY
DATA QUALITY REPORT
DATABASE SUMMARY
VERIFIED DATABASE
STATISTICAL SUMMARY
INTERPRETIVE REPORT
INTEGRATED ASSESSMENT

Figure 11.1 Sequence of reporting in EMAP-Forests.

ecosystems. Technical proceedings provide an opportunity for analysts to summarize and publish findings and research and to document monitoring techniques and procedures.

11.2.2 Review and Clearance Procedures

In general, both the EPA and the FS have similar review and clearance procedures. They include informal peer review, formal peer review, laboratory/station clearance, and Washington Office clearance if needed.

Cooperative monitoring could require review and clearance of multi-agency reports by several agencies. EMAP-Forests recommends the establishment of an interagency (including but not necessarily limited to EPA-EMAP and FS-FHM) monitoring review committee to facilitate the review and clearance of interagency reports.

If a document has single agency authorship, publication and distribution is handled by that agency. It must also pass through the interagency review committee prior to agency clearance by the authoring agency. If a document has interagency authorship, a pre-designated agency handles publication and distribution. For clearance it must pass through the interagency review committee and clearance procedures for both agencies. Pre-designated authorship of various reports should be agreed upon early in the program.

11.3 FOREST MONITORING PLANS

The rationale for the interagency monitoring program is described in regional and national research plans. These plans include monitoring design, data analysis, indicator development, and assessments. The implementation intentions of the multi-agency program are described in regional work plans that include program management, field and laboratory logistics, QA, information management, and reporting. Research and work plans consider essential linkages and coordination with other groups. For example, research plans consider intra- and inter-coordination among EMAP and FHM monitoring tiers, and the work plans consider coordination with other agencies for data collection and reporting.

Research plans are difficult to anticipate; flexibility is essential. The participating agencies will prepare separate or multi-agency, national or regional, research plans with frequencies and contents that depend on their separate and mutual needs. A separate agreement for cooperative research will usually accompany each inter-agency research plan.

Annual regional work plans will have multi-agency authorship and will be published and distributed by the FS. The EPA will be primarily responsible for QA, information management, air quality and deposition, meteorology, and laboratory sample collection and analysis sections. The FS will be primarily responsible for field data collection sections. Program management and reporting sections will be co-authored.

The target publication date for regional work plans is June 30. The publication of annual work plans should precede data collection by at least one year. For example, work plans produced during FY95 would specify data collection for FY96. This scheduling allows FY95 planning to make use of Agency budget projections from FY94, and the lead time allows full organization of data collection. The multi-agency program is currently operating on a compressed planning schedule. One way to maintain current activities while moving to the desired schedule is to prepare a single two-year work plan in FY92 (for FY 92 and FY 93 field work) to be followed by the annual plans starting in FY93 (for FY 94 field work).

The QAPP and QAPjP are described in Section 8.

In contrast to this strategy for plans, the first national plan (scheduled for 1992) will be a multi-agency research and work plan that will guide initial implementation and set the stage for additional research. Publication and distribution of this plan have not been determined.

11.4 OPERATIONS REPORTS

An annual operations report describes activities completed during the preceding data collection cycle, evaluates the performance of the monitoring program, and includes recommendations for future work plans. These reports have multi-agency authorship and are published and distributed by the EPA (national) and by the FS (regional). The target publication dates are Jan. 30 (regional) and March 30 (national) of the year following data collection.

11.5 DATA BASE SUMMARIES

Data base summaries are needed for three reasons. First, their publication signals the existence of, and describes access to, a validated data base that is available for data analyses. A second purpose for the data base summary is subtle but important. In an interagency program, the report is a vehicle for participants to agree what the data are as opposed to what the data mean. The distinction will enable data analyses to proceed from an agreed-upon, common data base, even if different conclusions are reached by different analysts. This should eliminate the question of whether different conclusions result from different interpretations or different data bases. Finally, the data base summary provides an unambiguous reference for the specific versions of the data base that are used in any analyses.

The data base summary describes all verified data (field and laboratory) collected by the FHM program, as well as summaries (only) of off-frame data that may be prepared specifically for EMAP-Forests assessment purposes. Data collected or summarized by other EMAP Task Groups, for example EMAP-Air and Deposition or EMAP-Landscape Characterization, will be treated by separate summaries prepared by those groups.

The data description should include a data dictionary, formats, logical relations among data base tables, and instructions for access to data and QA information. It should also describe the amount of data contained in various data base tables for different years and regions of the country.

The data base summary is produced annually in addition to other information management reports (see Section 10). Because laboratory analyses, data verification, and QA analyses require time beyond the "field season" for completion, the data base summary is scheduled for a June 30 publication date.

A single, national, data base summary will be prepared by FHM and will be published and distributed by the Forest Information Center. The format will be comparable to other EMAP resource group data base summaries, thus providing all forest analysts easier access to all ecosystem data that may be managed by the overall EMAP Information Center (EIC).

11.6 DATA QUALITY REPORT

EMAP-Forests adheres to EPA requirements for QA and quality control (QC). These requirements include certain types of planning and evaluation reports (see Section 8). The data quality report, like the data base summary, is designed specifically to assist analysts who use the FHM data base. The purpose is to provide analysts with a concise summary of the quality of the verified data that are contained in the data base. Data quality statistics and other descriptors are essential for analysts so that the uncertainty of assessments can be quantified.

All field and laboratory data collected by the FHM program will be included, but data derived from auxiliary sources will be excluded from data quality reports. The quality of auxiliary data will be reported separately by the collecting agencies.

Data quality descriptors may include detectability, precision, accuracy, comparability, and completeness. Measures of uncertainty associated with system error may be included.

The data quality report should be prepared in a format that is very similar to the data base summary. Like the data base summary, this report is scheduled for an annual June 30 release in the year following data collection. A single, national data quality report will be prepared by EMAP-Forests and will be published and distributed by the EPA.

11.7 STATISTICAL SUMMARY

The statistical summary is designed to provide timely descriptions of regional status and trends of forest indicators monitored by EMAP (see Section 3). The statistical summary will rely mainly on pre-planned ("canned") analyses to produce compatible reports among regions and over time. Such analyses produce timely reports, but do so at the expense of novel analyses and interpretations. Therefore, these reports are not designed to diagnose specific causes of specific changes in forest condition, to track the recovery of particular forests in response to particular control and mitigation programs, or to report data from non-EMAP sources. Pre-planned summaries may include EMAP data collected off the forest sampling frame (e.g., air quality, weather, and landscape characterization data).

The statistical summary will highlight the regional status and trends of forest condition and environmental stresses and exposure in terms of a few key indicators because it is not feasible to report all the measurements of forest structure, function, and composition, as well as measurements of environmental stresses and exposure, in a concise format.

The statistical summary may also show associations among indicators if the associations are either pre-planned or known to be non-controversial. This may be hard to define. It is appropriate to use known associations to identify potential "false positives" that might otherwise be cause for undue concern. For example, an association between abnormal growth rates and abnormal rainfall would be appropriate because there is no real controversy about an underlying causal relationship. The discussion of these associations must emphasize that correlation implies neither causality nor degree of effect. One criterion of whether or not to include a particular association will be interagency clearance.

When a change in a given indicator is small in relation to the uncertainty about components of the indicator, conclusions might be erroneous. Thus, the appendices of the statistical summary will provide estimates or other indications of measurement and population uncertainties for each of the reported indicators.

Prototypes of the statistical summary (albeit with different indicators) include the "core tables" common in FS FIA state reports. These prototypes illustrate that raw data can be summarized for routine and timely reporting in a fashion that is consistent among regions and over time. Early reports from the FS-FHM program utilize the "core table" concept. Table 11.3 suggests an outline for a typical statistical summary.

Regional and national versions of the statistical summary will be prepared annually. The regional version is scheduled for a September 30 release in the year following data collection. The national version of this report is also scheduled for a September 30 release.

Statistical summaries will have interagency authorship. The FS will assume responsibility for publication and distribution of regional reports, and the EPA will oversee publication and distribution of national reports.

EMAP-Forests recommends that data are released to the general public after publication of the regional statistical summaries (i.e., within one year after data are collected). Prior to this release, verified data may be accessed only by analysts authorized by the interagency management structure.

11.8 INTERPRETIVE REPORTS

The interpretive reports are designed to provide deeper analysis and assessment of regional status and trends in forest condition. In general, these reports are not designed to diagnose specific causes of specific changes in forest condition. An exception is to track the recovery of particular forests in response to particular control and mitigation programs, where supported by particular measurements and procedures that augment the basic monitoring (Tiers 1 and 2) design. The deeper analyses can, however, suggest plausible causes of changes and explore alternatives in much more detail than can be accomplished in the statistical summaries.

These reports may utilize data from other EMAP resource groups and from non-EMAP sources. They may consider the several tiers of monitoring, explore the sensitivity of apparent associations to varying assumptions, and offer multiple interpretations of status and trends.

The scope and content of these reports is being discussed by EMAP and by FS-FHM in the context of each total monitoring-research program. At a minimum, it is recommended that regional and national interagency interpretive reports of forest condition be prepared every three to five years. These reports will be aimed at interpreting the status and trends previously reported in the statistical summaries. The reports will have multi-agency authorship. The regional reports will be published by the FS and the national reports by the EPA. Publication and distribution dates of these multi-agency efforts has not been determined.

In addition, EMAP-Forests will participate every three years in EMAP-wide integrated assessments that are coordinated by the overall EMAP Integrated Assessment Strategy. These reports will draw on forest and other ecosystem data bases, will be authored by the EPA and other agencies, and will be published and distributed by the EPA. Among other uses, these reports are a link to the EPA risk assessment reports.

11.9 TECHNICAL PROCEEDINGS

It is recommended that the interagency program sponsor technical conferences where cooperators would have the opportunity to present their most recent findings or research. It is further recommended that the program publish a series of monitoring research and applications reports

Table 11.3 Typical outline of a statistical summary.

I. Executive summary

- A. Statement of forest extent: What is the current extent of forest ecological resources, and how are they distributed geographically?
- B. Statement of forest condition: What proportions of the forest resources are currently in good or acceptable condition?
- C. Statement of regulatory concern: What proportions are degrading or improving, in what regions, and at what rate?
- D. Recommendations for monitoring and research.

II. Methods

- A. Forest data collection.
- B. Auxiliary data access.
- C. Bio-geo-statistical methods
  - Sampling, classification, and stratification
  - Estimation of indicators and indices
  - Statistical estimation of status and trends
  - Special displays of information
- D. Interpretive methods and caveats.

III. Results

- A. Status and extent of apparently "healthy" forests.
- B. Status and extent of apparently "unhealthy" forests.
- C. Regional patterns and trends of forest health.
- D. Regional patterns and trends of weather and pollution.
- E. Atlases and spatial/temporal correlations.

IV. Discussion

- A. Status and trends of forest condition in relation to trends of environmental stresses.
- B. Possible/plausible associations (caveated).

V. Appendices

- A. Data uncertainty estimation.
- B. Data tables and documentation.

as part of this conference. The purpose of these publications is to document analysis procedures and findings that would otherwise not be appropriate for peer-reviewed journals and would be lost with employee turnover. A quarterly proceedings would be edited by members of the interagency review committee and/or advisory boards and published by the FS.

11.10 ORGANIZATION OF REPORTING EFFORT

The purpose of this section is to assign, within EMAP-Forests, responsibilities for contributions to the reports mentioned in the previous sections.

It is premature to suggest specific staffing requirements. However, the EMAP-Forests staffing strategy should emphasize extramural participation and cooperation to avoid duplicating efforts and accumulating a large in-house staff. A minimum in-house staff will be responsible for technical areas in which the EPA makes a unique contribution such as air quality, weather, and deposition. This staff will also coordinate EMAP-Forests assessments and reporting and provide analytical services needed by many cooperators. Justification for "analytical services" comes from familiarity with the EMAP-wide data bases. In most cases, EMAP-Forests reporting personnel will have additional regional and national implementation or research responsibilities.

A reporting organization for EMAP-Forests is depicted in Figure 11.2. A national reporting unit and four regional units that are coordinated by the national unit are required. Regional units will be responsible for cooperative reporting within their assigned region (currently defined as FS mega-regions [Figure 11.3]: North-Northeast, South-Southeast, Rocky Mountain-Intermountain, and Pacific Northwest-Pacific Southwest). The national unit will be responsible for cooperative national reporting and for coordinating the reporting by regional units.

Reports will be written by both "implementation" and "assessment" personnel. Implementation personnel will oversee contributions to work plans, operations reports, data base summaries, and data quality reports. Assessment personnel will assume responsibility for contributions to statistical summaries, interpretive reports, and integrated assessments. Both groups contribute to the Interagency Monitoring Plan, research plans, and the proceedings series.

Table 11.4 summarizes the EPA laboratory and national reporting assignments. These assignments maintain regional implementation and assessment reporting capabilities and assign national leadership roles that are consistent with EMAP's current national assignments of laboratory roles. Assignments of individual EPA Laboratories to mega-regions are anticipated in FY91 or FY92.

The one exception to the regional-national alignment within EPA is that both national and regional units are assigned to national interpretive reports. EMAP-Forests scientists are organized according to assessment topics with a national perspective; therefore, participation by all regional units in all regional and national interpretive reports is possible. In some cases, individual regional units may be assigned, based on laboratory expertise, to complete particular interpretive reports. The national unit is identified specifically to recognize a closer association with the overall EMAP Integration and Assessment Project, focusing on EMAP-wide integrated assessments, and to coordinate regional and national interpretive reports.

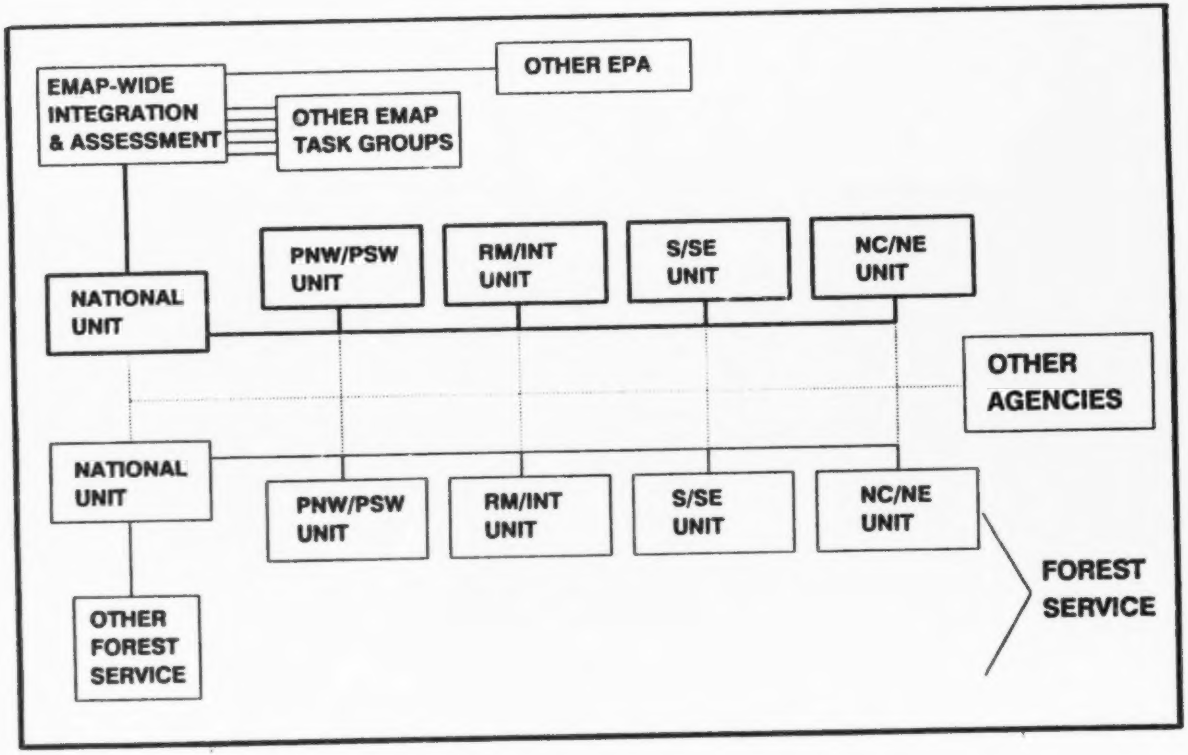
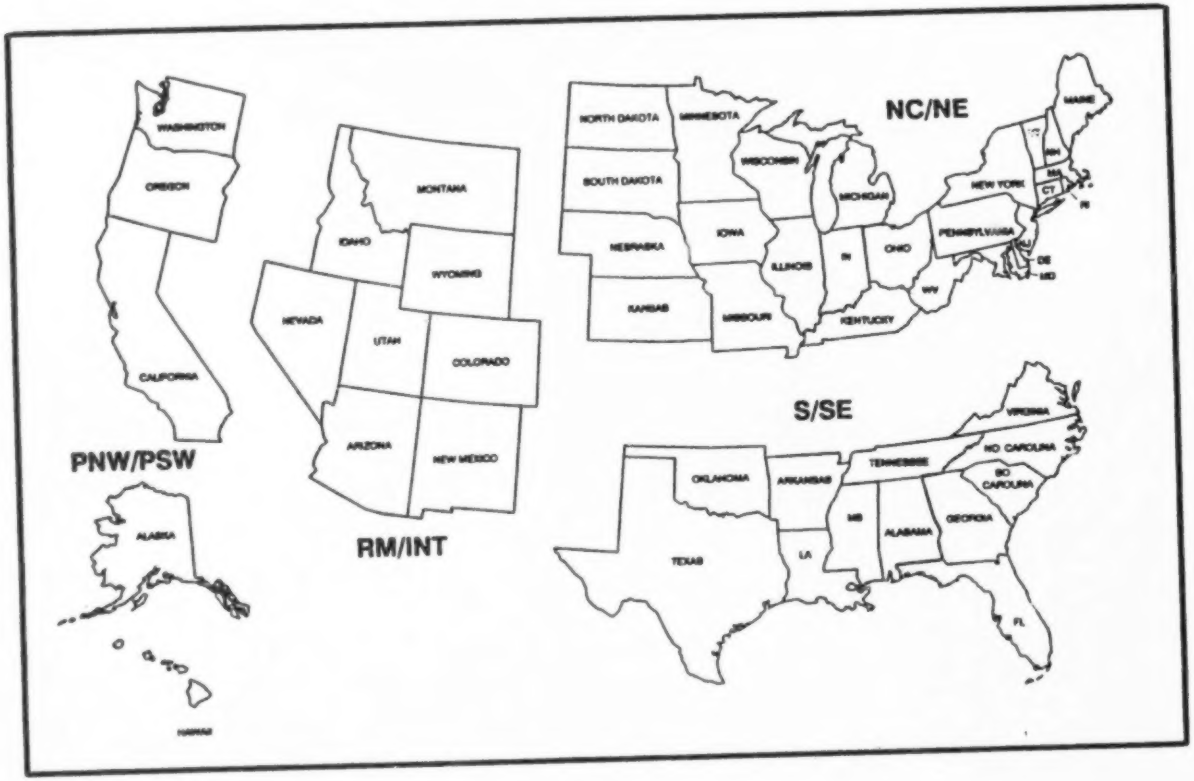

EMAP-WIDE INTEGRATION & ASSESSMENT
OTHER EPA
OTHER EMAP TASK GROUPS
NATIONAL UNIT
PNW/PSW UNIT
RM/INT UNIT
S/SE UNIT
NC/NE UNIT
OTHER AGENCIES
NATIONAL UNIT
PNW/PSW UNIT
RM/INT UNIT
S/SE UNIT
NC/NE UNIT
FOREST SERVICE
OTHER FOREST SERVICE

Figure 11.2 EMAP-Forests reporting organization and liasons.


NC/NE
S/SE
RM/INT
PNW/PSW
WASHINGTON
OREGON
CALIFORNIA
ALASKA
HAWAII
MONTANA
IDAHO
WYOMING
NEVADA
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
MINNESOTA
IOWA
MISSOURI
WISCONSIN
ILLINOIS
MICHIGAN
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OHIO
KENTUCKY
WV
PENNSYLVANIA
NEW YORK
VT
NH
MAINE
MA
CT
RI
NJ
DE
MD
OKLAHOMA
TEXAS
ARKANSAS
LA
MS
ALABAMA
TENNESSEE
GEORGIA
FL
SO CAROLINA
NO CAROLINA
VIRGINIA

Figure 11.3 Forest service mega-regions.

Table 11.4 Laboratory and national reporting unit assignments to produce documents described in this chapter for EMAP-Forests[a]

Staff type and report type	National unit	Regional units
Implementation staff:		
Regional Implementation Plan and Operations Report		EMSL-LV ERL-C AREAL-RTP
National Implementation Plan and Operations Report	EMSL-LV	
Data base Summary	EMSL-LV	
Data Quality Report EMSL-LV		
Assessment staff:		
Regional Statistical Summary		EMSL-LV ERL-C AREAL-RTP
National Statistical Summary	AREAL-RTP	
Regional Interpretive Report		EMSL-LV ERL-C AREAL-RTP
National Interpretive Report and EMAP Integrated Assessments	AREAL-RTP	EMSL-LV ERL-C AREAL-RTP

[a] Excludes Research Plans and Proceedings.

11.11 ACTION PLAN

The plan for the evolution of reporting capabilities assumes a phased, regional implementation of monitoring and coincident need for reporting. There is a need within EMAP-Forests for regional capabilities in the North-Northeast and South-Southeast regions. In FY92, or FY93 at the latest, the other two mega-regions will require reporting capabilities. There is also a need to organize the national reporting capability within EMAP-Forests, especially with regard to EMAP-wide assessments.

With respect to the interagency reporting strategy, the following specific recommendations are made:

- Utilize this strategy document as a basis for reaching a formal interagency agreement (IAG) in FY91 on:

1) The regional-national, implementation-assessment framework.
2) The types of reports and the roles of each agency.
3) The review, clearance, and scheduling of reports.

- Allow for extramural (i.e., non-FS and non-EPA) participation in reporting as part of the IAG and circulate a joint strategy later in FY91 to invite such participation.
- Identify an interagency review committee in FY91.
- Include a multi-agency plan for reporting in the Interagency Plan scheduled for FY92.
- EMAP-Forests should identify regional reporting units for the two eastern mega-regions in FY91 and for the two western mega-regions no later than FY92.
- EMAP-Forests should identify the specific roles and responsibilities for the national reporting units in FY91.
- The FS should identify national reporting units in FY91.
- The EPA and the FS should achieve the 3-year planning, implementation, and reporting schedule by FY93 at the latest. This mainly affects the length of the planning horizon in FY92.
- Include regional and national reports as deliverables in the EMAP-Forests budgeting process starting in FY92.

With respect to strictly EPA reporting requirements, the following specific recommendations are made:

- The national reporting unit should be available to participate in the overall EMAP-Integration and Assessment Project (AREAL-RTP) strategies and plans in FY91-FY92.
- As appropriate, the overall EMAP-Integration and Assessment Project should include EMAP-Forests personnel and EMAP-Forests data bases in "example integrated assessments" that may be planned for FY91-92.

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13 GLOSSARY (after Hunsaker and Carpenter 1990)

Area frame - A sampling frame obtained by dividing a region into well-defined, identifiable subregions that in aggregate comprise the total area of the region of interest. The subregions are sampling units defined on maps or other cartographic materials.

Assessment endpoint - A quantitative or quantifiable expression of the environmental value being considered in the environmental analysis; examples include a 25% reduction in gamefish biomass or local extinction of an avian species (Suter 1990).

Association rule - A rule that unambiguously links a single resource sampling unit with a grid point if there are any resource units in the 40-hex centered at that grid point. Several such rules have been identified in selecting a Tier 2 sample via the EMAP grid.

Augmented sample - A grid-based sample whose size has been increased by using a denser grid.

Best management practices - Management practices targeted at minimizing specific watershed disturbances, such as soil erosion, pollutant transport, stormwater runoff, or similar land-use-related disturbances.

Bias - In a sampling context, the difference between the conceptual weighted average value of an estimator over all possible samples and the true value of the quantity being estimated. An estimator is said to be unbiased if that difference is zero.

Biodiversity - A conceptual term referring to the variety and variability among living organisms and the ecological complexes in which they occur; diversity can be defined as the number of different items and their relative frequencies. For biological diversity, these items are organized at many levels, ranging from complete ecosystems to the chemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, genes, and their relative abundance (OTA 1987).

Biomarker - An indicator of cellular or physiological processes that signal events in biological systems or samples. A biological marker of effect may be an indicator of an endogenous component of the biological system, a measure of the functional capacity of the system, or an altered state of the system that is recognized as impairment or disease. A biological marker of exposure may be the identification of an exogenous substance within the system, the interactive product between a xenobiotic compound and endogenous components, or other event in the biological system related to the exposure (NRC 1987).

Bottom-up approach - Assessing ecological condition based on first principles, i.e., pollutant effects are related causally to pollutant sources by transport and fate models.

Candidate Indicator - Indicator identified for each resource category by using a combination of literature review, expert workshops, and interviews with scientists and environmental managers, which was then judged against specific EMAP criteria to determine its feasibility as a research indicator.

Characterization - Determination of the attributes of resource units, populations, or sample units. A prominent use in EMAP is characterization of 40-hexes.

Classification - The process of assigning a resource unit to one of a set of classes defined by values of specified attributes. Example: forest sites will be classified into the designated forest types, depending on the species composition of the forest.

Core Indicator - EMAP indicator that is selected for long-term, routine monitoring based on its performance as demonstrated in a regional demonstration project.

Cumulative frequency distribution - A distribution generated by a function (F(x)) such that at any value for the variable x, F(x) represents the proportion of the resource sampling units in the target population having a value for the variable that is less than or equal to x. In EMAP, x is usually a measurement of physical extent or an indicator measurement.

Deconvolution - Extraneous variation such as random errors in measurement has the effect of inflating observed variation relative to true population variation. The cumulative distribution function (cdf) that will be estimated when extraneous variation is present is the convolution of the population (which is the cdf of interest) and the distribution of the extraneous variable. The convolution cdf will be flatter (have longer tails) than the population cdf. Deconvolution is the process of removing the influence of extraneous variation from an apparent cdf.

Developmental Indicator - An EMAP indicator that has passed evaluation for expected performance (existing data analyses, simulation, and small-scale field tests) and, with the concurrence of scientific peer reviewers, is deemed suitable for actual performance testing in a regional demonstration project.

Diagnostic Indicator - Characteristics of the environment measured for the purpose of correlative analysis to determine plausible explanations for subnominal conditions; a collective term for EMAP exposure, habitat, and stressor indicators.

Digital line graph (DLG) - A standard U. S. Geological Survey computer format for representing linear features of the earth, such as streams and roads, as they appear on maps.

Ecological Indicator - Response indicator.

Ecological resource category (resource category) - The aggregations of ecological resource classes that are conveniently dealt with by ecologists with specific disciplinary expertise; six categories currently are identified: near-coastal waters, surface waters, wetlands, forests, arid lands, and agroecosystems. ecosystems.

Ecological resource class (resource class) - A subdivision of an ecological resource category; examples include small lakes, oak-hickory forests, emergent estuarine wetlands, field cropland, mesohaline estuaries, and sagebrush dominated desert scrub.

Ecological risk assessment - The application of a formal framework to estimate the effects of human action on a natural resource and to interpret the significance of those effects in light of the uncertainties identified in each component of the assessment process. Steps in the framework include initial hazard identification, exposure assessment, dose-response assessment, and risk characterization.

Ecosystem - A local complex of interacting plants, animals, and their physical surroundings which is generally isolated from adjacent systems by some boundary, across which energy and matter move; examples include a watershed, an ecoregion, or a biome.

Ecosystem function - Attributes of the rate of change of structural components of an ecosystem; examples include primary productivity, denitrification rates, and species fecundity rates.

Ecosystem structure - Attributes of the instantaneous state of an ecosystem; examples include species population density, species richness or evenness, and standing crop biomass.

Environmental indicators - A collective term for response, exposure and habitat, and stressor indicators.

Explicit sampling frame - The representation of a target population (resource category, class, or subclass), each unit of which has a unique identification code, used to implement a sampling strategy; an example includes a list of all lakes greater than 4 ha in the Northeast.

Exposure indicator - A characteristic of the environment measured to provide evidence of the occurrence or magnitude of a response indicator's contact with a physical, chemical, or biological stress.

Grid enhancement - Increasing the grid density; method for augmenting the sample. When the Tier 1 sample size is too small, as will occur for rare resources, the grid density may be increased in order to obtain a sample size adequate for population description.

Grid, triangular (EMAP) - A lattice of points in exact equilateral triangular structure. The EMAP grid points are 27.1 km apart.

Grid, baseline (EMAP) - The fixed position of the EMAP grid as established by the position of the global hexagon covering the United States. This is distinguished from the random position of the grid as used for sampling.

Grid randomization - The process of randomly positioning the grid so that each (compact and small) unit of area of fixed size is equally likely to contain a grid point. This is the basis for the probability-sample designation of the EMAP sample.

Habitat Indicator - A physical attribute measured to characterize conditions necessary to support an organism, population, or community in the absence of pollutants.

Hazard - A state that may result in an undesired event; the cause of risk. In EMAP, any human-related event or activity that unintentionally or inadvertently can affect ecological condition; examples are acidic deposition that may decrease the acid-neutralizing capacity of surface water, or application of fertilizer to a forested watershed that may increase nutrient levels in adjacent streams.

Hazard Indicator - Measures that reflect human activities that unintentionally affect ecological resources (e.g., measures of pollutant release, number of permits issued for construction activity, and rates of application of fertilizers to forests and crops that influence nutrient concentrations in adjacent streams).

Hexagon - A regular six-sided polygon. A tessellation of hexagons is the dual of a triangular point grid; each point in the grid is the center of a hexagon, and the hexagons tile the surface. These hexagons on the EMAP grid have size of 634.5 km.

40-hex - The landscape description hexagon that is established on each of the grid points in the EMAP grid. Actual size of these hexagons is 634.5 / 16 = 39.7 km^2.

Hierarchical (grid) - Having nested levels and structure. Density of the EMAP grid is readily increased or reduced in a regular manner into hierarchical levels of density. Adjacent levels may differ in density by a variety of factors: 3, 4, 7 or many combinations of these base factors. Typically, the grid of points at one level will be contained in the grid at a higher density.

Implicit-sampling frame - A set of rules or criteria used to select resource sampling units that cannot be listed *a priori* by a unique identification code (upon which indicators will be measured); the rules are developed as part of the landscape characterization activities performed on the landscape sampling units.

Inclusion probability - The probability of including a specific sampling unit in the sample.

Index (Indices) - Mathematical aggregation(s) of indicators or metrics; one example is the Index of Biotic Integrity (IBI), which combines several metrics describing fish community structure, incidence of pathology, population sizes, and other characteristics.

Index period - Sampling period that yields the maximum amount of information during the year, which may vary from one indicator or resource class to another.

Indicator - A characteristic of the environment that, when measured, quantifies the magnitude of stress, habitat characteristics, degree of exposure to the stressor, or degree of ecological response to the exposure.

Interpenetrating design - The monitoring survey design used in EMAP, in which a new set of resource sampling units (RSUs) is selected each year during four successive years. The four-year cycle is repeated by using the same set of RSUs as in the first cycle; therefore, the same set of RSUs sampled in year 1 would be resampled in year 5.

Kriging - A weighted, moving-average estimation technique based on geostatistics that uses the spatial correlation of point measurements to estimate values at adjacent, unmeasured points.

Landscape - The fundamental traits of a specific geographic area, including its biological composition, physical environment, and anthropogenic or social patterns.

Landscape characterization - The documentation of principal components and patterns of landscape structure, including attributes of the physical environment, biological composition, and cultural patterns. In EMAP, a term referring to the process of describing land use or land cover within the landscape sampling units.

Landscape ecology - The study of the distribution patterns of communities and ecosystems, the ecological processes that affect those patterns, and changes in pattern and process over time (Forman and Godron 1986).

Landscape indicator - A characteristic of the environment, calculated from remotely sensed data, used to describe spatial distribution of physical, biological, and cultural features across a geographic area.

Landscape sampling unit - The selected units (e.g., 40-km^2 hexagons) upon which landscape characterization will be performed.

Management indicator - Measures that reflect human activities that intentionally alter an ecological resource to meet some management objective; for example, the dredging or filling of a wetland for the purpose of housing development.

Maximum/minimum operators approach - A mathematical aggregation scheme used to produce an ecological condition index based on several response indicator values; the index assumes the value of the most subnominal indicator.

Natural process indicator - Measures that reflect cyclic or acyclic phenomena that affect ecological condition, regardless of the presence of management actions or environmental hazards; examples include natural climatic fluctuations, predator-prey cycles, and insect and disease epidemics.

Nominal - The state of having desirable or acceptable ecological condition.

Population estimate - A statistical estimate of some characteristic (or distribution of characteristics) that applies to an explicitly defined target population (category, class, or subclass), e.g., the median acid-neutralizing capacity (or the cumulative frequency distribution of acid-neutralizing capacity) for all small lakes in the Northeast.

Probability sample/sampling - A sample chosen in such a manner that the probability of each selected unit is known; for EMAP, each resource sampling unit (e.g., a lake, a forest, an estuary) upon which indicator measurements are to be made will have a known probability of being selected.

Randomization - The process of imposing an element of chance on the selection of a sample. This may take many forms; this step of the design protocol is the basis for determining "design-based" properties.

Region - Any extensive geographic area that generally corresponds in size to EPA administrative Regions III through X (e.g., physiographic regions, ecoregions, major river basins).

Regional ecological resource class (regional resource class) - An ecological resource class that is distributed over some natural spatial range, e.g., southeastern oak-hickory forests or small lakes in the Northeast.

Regional reference site - One of a population of benchmark or control sites that, taken collectively, represent an ecoregion or other broad biogeographic area; the sites, as a whole, represent the best ecological conditions that can be reasonably attained, given the prevailing topography, soil, geology, potential vegetation, and general land use of the region.

Research Indicator - A candidate indicator identified for an EMAP resource category which has been prioritized on the basis of several criteria (e.g., regionally applicable, integrates effects, monotonic, conducive to synoptic monitoring) and, following peer review, has been selected for further evaluation for use in EMAP, as possible developmental indicators; evaluation of expected performance includes analyzing existing data, performing simulation studies with realistic scenarios and expected spatial and temporal variability, and conducting limited field tests.

Resource sampling unit - A particular ecological resource (e.g., a stream segment, a forest stand, a wetland, an estuary) upon which indicator measurements will be made; more than one resource sampling unit can occur in a landscape sampling unit.

Response Indicator - A characteristic of the environment measured to provide evidence of the biological condition of a resource at the organism, population, community, or ecosystem process level of organization.

Sample - A subset of the units from a frame. A sample may also be a subset of resource units from a population or a set of sampling sites.

Sampling design - A sample consists of a set of sampling units or sites that will be characterized. Sampling units are defined by the frame; they may correspond to resource units, or they may be artificial units constructed for the sole purpose of the sampling design.

Stratum/strata - A stratum is a sampling structure that restricts sample randomization/selection to a subset of the frame. Inclusion probabilities may or may not differ among strata.

Stressor indicator - A characteristic measured to quantify a natural process, an environmental hazard, or a management action that effects changes in exposure and habitat.

Stressor - Measurements used to provide information on human activities or externalities that can cause stress in ecological entities; three types of stressor indicators are considered in EMAP; hazard indicators, management indicators, and natural process indicators. Examples are the incidence of fertilizer application, which can increase nutrient concentrations in lakes; incidence of dredging/filling, which can diminish availability of wetland habitat; and climatic fluctuations, which can promote damage by pathogens.

Subnominal - The state of having undesirable or unacceptable ecological condition.

Systematic sample - A sampling design that utilizes regular spacing between the sample points, in one sense or another. The EMAP design selects samples via the triangular grid; spatial arrangement of the selected resource units is not always strictly systematic, but the systematic grid is an important aspect of the design.

Target population - The set of ecological resources from which a sample is drawn.

Threshold - The value for a particular response indicator used to distinguish nominal from subnominal ecological condition.

Tier 1 resource sample - All resource sampling units of each resource class within all landscape sampling units.

Tier 2 resource sample - A subsample of the Tier 1 resource sample used for field sampling of indicators.

Top-down approach - Assessing ecological condition based on correlative analyses; i.e., pollutant effects are associated temporally or spatially with pollutant sources by statistically correlational analysis.

Validation - The process of determining the legitimacy of data, involving internal consistency checks for outlier removal and definition of levels of confidence.

Verification - The process of confirming the integrity of data, involving discrepancy, precision, and accuracy checks.

Weights - In a probability sample, the sample weights are inverses of the inclusion probabilities; these are always known for a probability sample. In other contexts, statistical weights are indicated for other reasons.

END